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FACULTY OF ENGINEERING SCIENCE

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ELECTROSTATIC BENEFICIATION OF COAL MINED AT HAT CREEK, BRITISH COLUMBIA TO MAKE LOW ASH CONCENTRATES

DSS UP W-88

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FINAL REPORT

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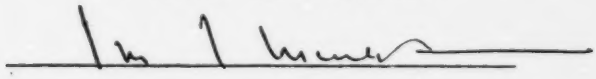

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MICROMEDIA

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A. GENERAL

i) Background of the Project

The coal deposits found in the upper Hat Creek Valley in British Columbia, with total reserves estimated to exceed several billion tons, contain a large percentage (up to 60%) of mineral matter (Ref. 1). On account of this, such coal could not be used directly in a power plant with conventional burners. Some prior beneficiation will be required. Furthermore, for economical transportation and storage reasons, any power generation project would require that both the burning of the coal and the disposal of the ash and of the rejects from the beneficiation process take place practically in situ. Environmental considerations in the Hat Creek Valley will very likely be of paramount importance in the evaluation of any beneficiation technology.

The results of this project, carried out by a research team of The University of Western Ontario, provide an additional picture in the spectrum of modern technologies available for cleaning coal.

Electrostatic beneficiation is a dry, physical separation process which can successfully handle particles in the 100 μm range - the size used in coal burners.

An investigation of a dry process was thought to be of special interest for the Hat Creek coal on account of the fact that its mineral matter is composed mostly of clay. Assuming that grinding the coal to minus 150 μm "liberates" the clay, the fraction rejected at the beneficiation process could be easily handled and disposed of in a dry state. [The settling velocity of a 100 μm spherical particle of density of 2 g/cm^3 in air at standard pressure and temperature is approximately

1.0 m/s.] By contrast, the washing of the same 100 μm clay particle could generate as many as one million 1 μm diameter clay particles which will stay in suspension in water for prolonged periods of time.

ii) Geology and Mineralogy of Hat Creek Coal
[From information released by B.C. Hydro]

Although considerable information is available on the overall geologic setting of the Hat Creek coal, only those aspects of the geology and mineralogy that are relevant to the current project will be discussed in any detail. The deposit is located in ~~northeastern~~ British Columbia and consists of some 600 m of low grade Tertiary age coal belonging to the Coldwater Formation. The coal sequence itself has been divised into four major zones of coal having the distinctly identifiable compositional characteristics discussed below. Up to 150 m of surficial soil and rock waste deposits overlie the central part of the basin of coal, increasing to over 300 m at the south end of the deposit.

a) General Description of Coal Zones

The uppermost Zone A coal consists of 170 to 205 m of variable quality coal containing numerous (more than 100) strata of waste rock varying in thickness from a few centimetres to 2 or 3 metres. An average interbed thickness of about 0.7 m characterizes the zone. The interbeds are composed of quartz, montmorillonite, kaolinite, feldspar and occasionally iron carbonate.

Zone B coal consists of 49 to 80 m of black, dull to bright coal with relatively few (~ 40), thin interbeds having an average thickness of only 20 cm. The interbeds consist essentially of kaolinite, quartz

and feldspar with occasional iron carbonate. Montmorillonite becomes considerably reduced in abundance in Zones B, C and D.

Zone C coal consists of 60 to 120 m of poor quality coal similar to that of Zone A. The interbeds are numerous (~ 50), vary in thickness from a few centimetres to 2 m, and average 40 cm in thickness. In composition, the interbeds consist essentially of kaolinite, quartz and occasional iron carbonate.

Zone D consists of good quality coal having a thickness of 60 to 120 m. The interbeds of waste, though numerous (~ 40), are thin averaging only 12 cm in thickness and consist of occasional tuff, ironstone and some resin.

b) Mineralogy of Interbeds in Coal Sequence

The clay mineralogy of the interbeds throughout the entire coal sequence is summarized in Fig. 1, which shows the relative amounts of the montmorillonite and kaolinite present versus depth. This figure gives no indication of the other constituents of the interbeds (quartz, feldspar, carbonate, etc.), nor the total ash content which is very variable depending on the detailed geology of each sample. The figure indicates clearly that montmorillonite is abundant in the Zone A interbeds and minor, negligible or absent in the Zone B, C and D interbeds. The actual ratio of montmorillonite to kaolinite averages about 3:7 in Zone A and 1:49 in Zones B, C and D.

c) Preliminary Mineralogy of Ash in Coal Sequence

The results of more detailed but still preliminary mineralogical studies of the ash mineralogy as supplied by B.C. Hydro are presented

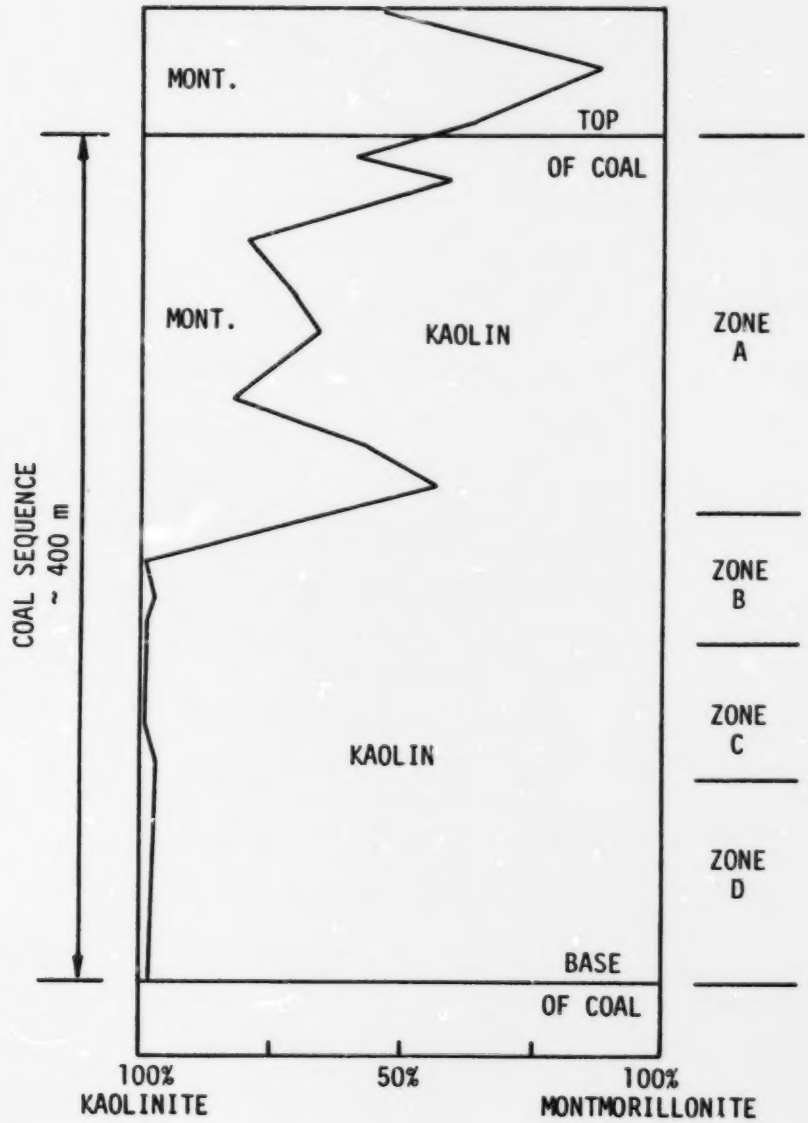


FIGURE 1. CLAY MINERALOGY OF COAL INTERBEDS
[Mineralogical data, courtesy B.C. Hydro]

in Figs. 2 and 3. The averaged summary plot in Fig. 2 shows the approximate mineralogy of the ash fraction from representative coal from B.H. #135 at Hat Creek. It is assumed that the major interbeds which can be wasted at the site during open pit mining are not included in the samples processed. The plot shows definite trends as follows:

1) Montmorillonite decreases from 40 or 50% of the ash at the top of Zone A to nearly zero in Zone B.
2) Quartz increases from about 20% of the ash at the top of Zone A to about 50% at the bottom of Zone D.
3) Kaolinite increases from about 15% of the ash at the top of Zone A to about 45% at the base of Zone D.
4) Feldspars average about 5% of the ash, decreasing slightly with depth.

A more detailed plot of composition versus depth is given in Fig. 3 to illustrate the actual variability of ash composition. Although the trends are obviously the same as in Fig. 2, the actual variations from sample to sample are enormous. Furthermore, there are scattered but presumably significant zones or layers of carbonate (siderite and ankerite) in the coal. A phosphate (goyazite) is also reported to dominate certain layers.

iii) Electrostatic Beneficiation Principles

At the basis of any electrostatic separation or beneficiation process for finely divided matter is the interaction between an external electric field and the electric charges acquired by the various particles. In any such processes, while the external field can be easily produced and

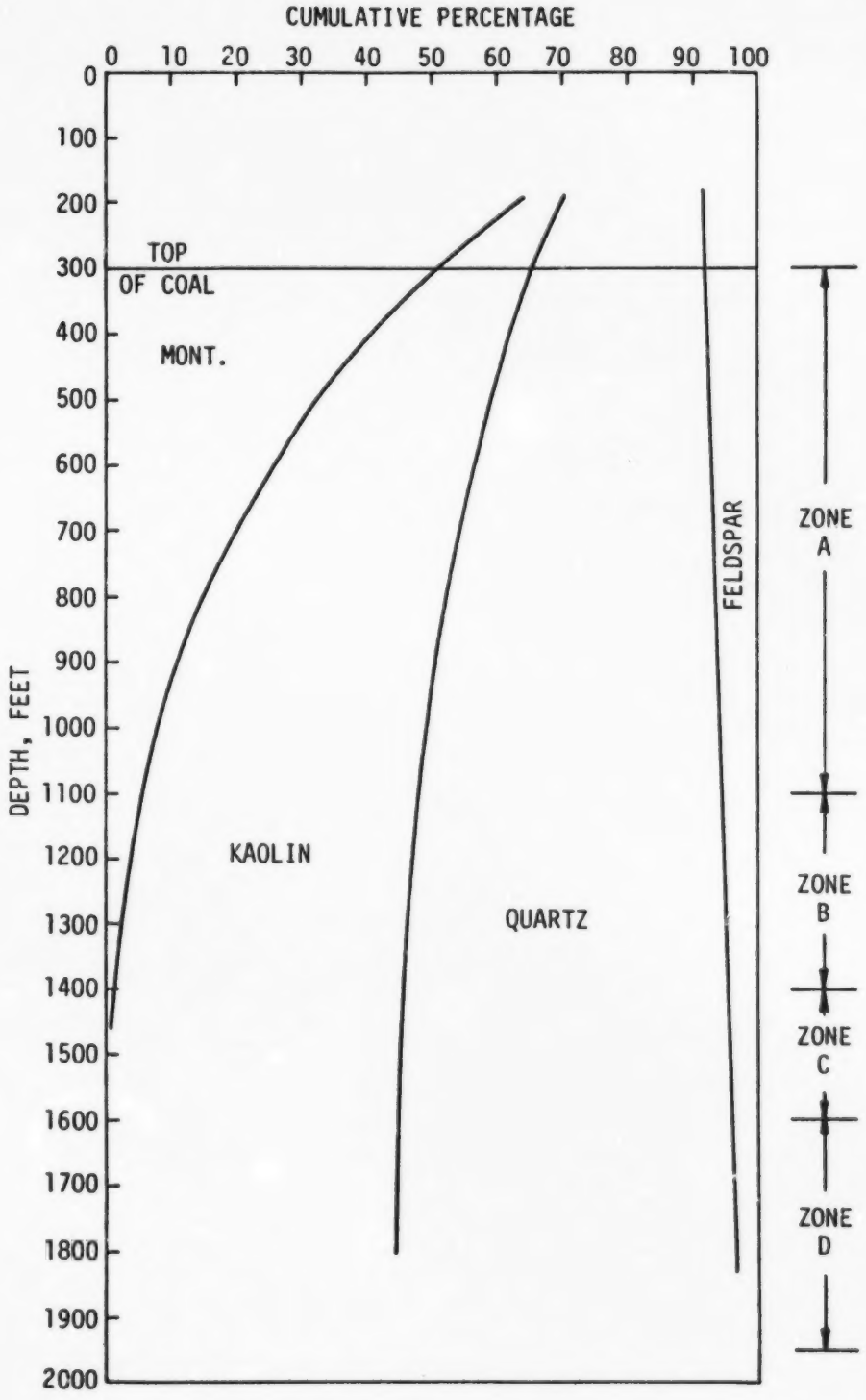


FIGURE 2. AVERAGED COMPOSITION OF ASH
[Mineralogical data, courtesy
B.C. Hydro]

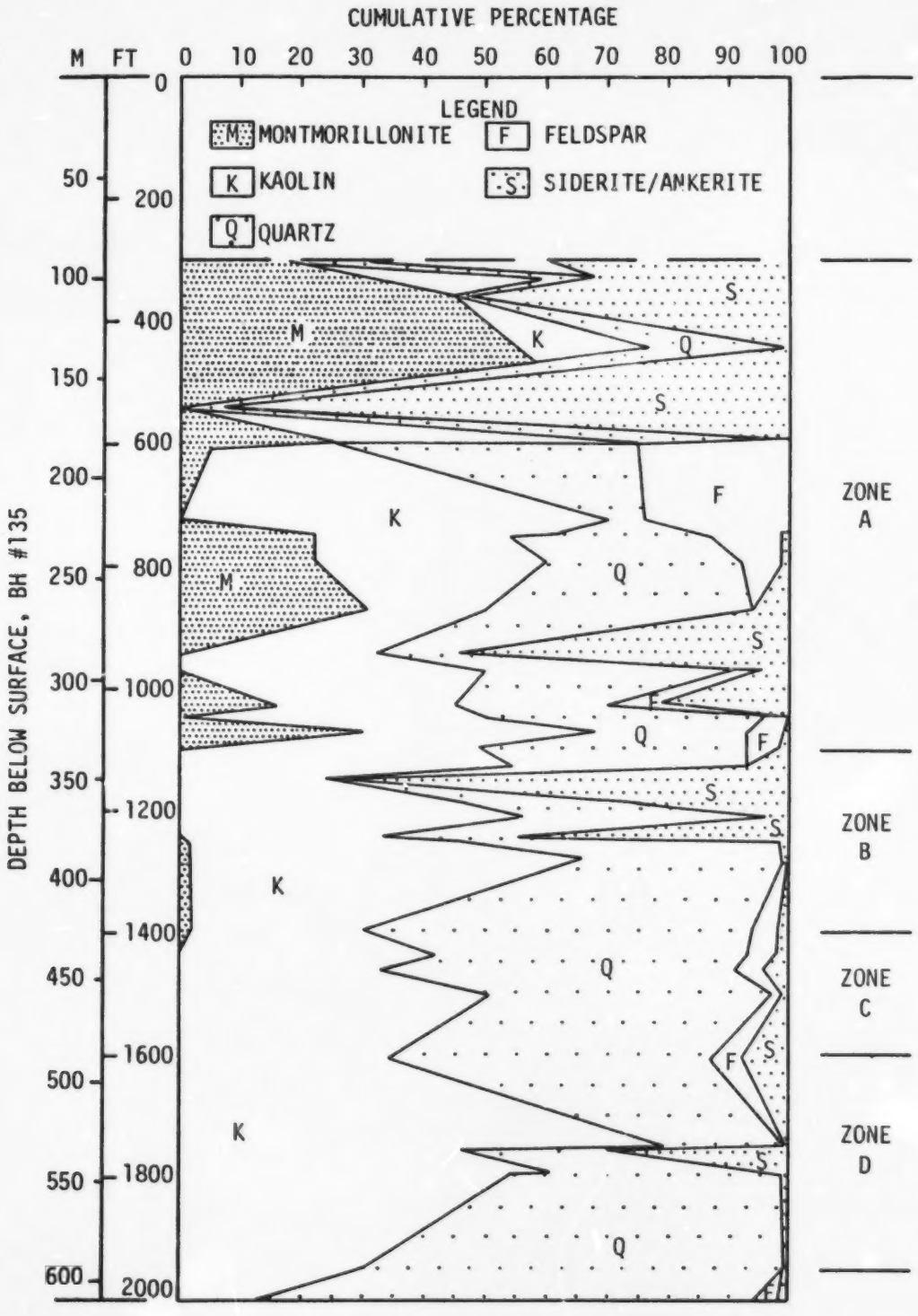

CUMULATIVE PERCENTAGE
M FT 0 10 20 30 40 50 60 70 80 90 100
LEGEND
M MONTMORILLONITE
F FELDSPAR
K KAOLIN
S SIDERITE/ANKERITE
Q QUARTZ
DEPTH BELOW SURFACE, BH #135
0 50 100 150 200 250 300 350 400 450 500 550 600
0 200 400 600 800 1000 1200 1400 1600 1800 2000
ZONE A
ZONE B
ZONE C
ZONE D

FIGURE 3. ASH COMPOSITION VS DEPTH
[Plotted from data for B.H. #135, courtesy B.C. Hydro]

controlled, the selective charging of the particles to be separated usually requires most of the development effort prior to the building of an industrial installation.

For the Hat Creek coal it was decided to use triboelectrification in a fluidized bed for the charging process.

Triboelectrification

The principle is shown schematically in Fig. 4. Let us assume that the particles placed on surface D are made to repeatedly contact one another as well as surface D. If W_A, the work function of the surface of particle A, is smaller than W_D, the work function of surface D, and W_D is smaller than W_B, the work function of the surface of particle B, then upon contact and separation particle A will become positively charged, particle B negatively charged, and surface D will respectively acquire electrons from particle A and give electrons to particle B.

Once the particles are charged selectively, and assuming that they are allowed to fall freely and under gravity forces in an applied horizontal electric field, they will acquire a horizontal acceleration component.

The horizontal acceleration intensity and direction are determined by the polarity and magnitude of the charge, by the direction and magnitude of the electric field and by the mass of the particle. Positively charged particles will move in the direction of the field, negatively charged particles will move in a direction opposite to that of the field. The initial horizontal acceleration of each particle will be proportional to its charge to mass ratio and to the intensity of the electric field.

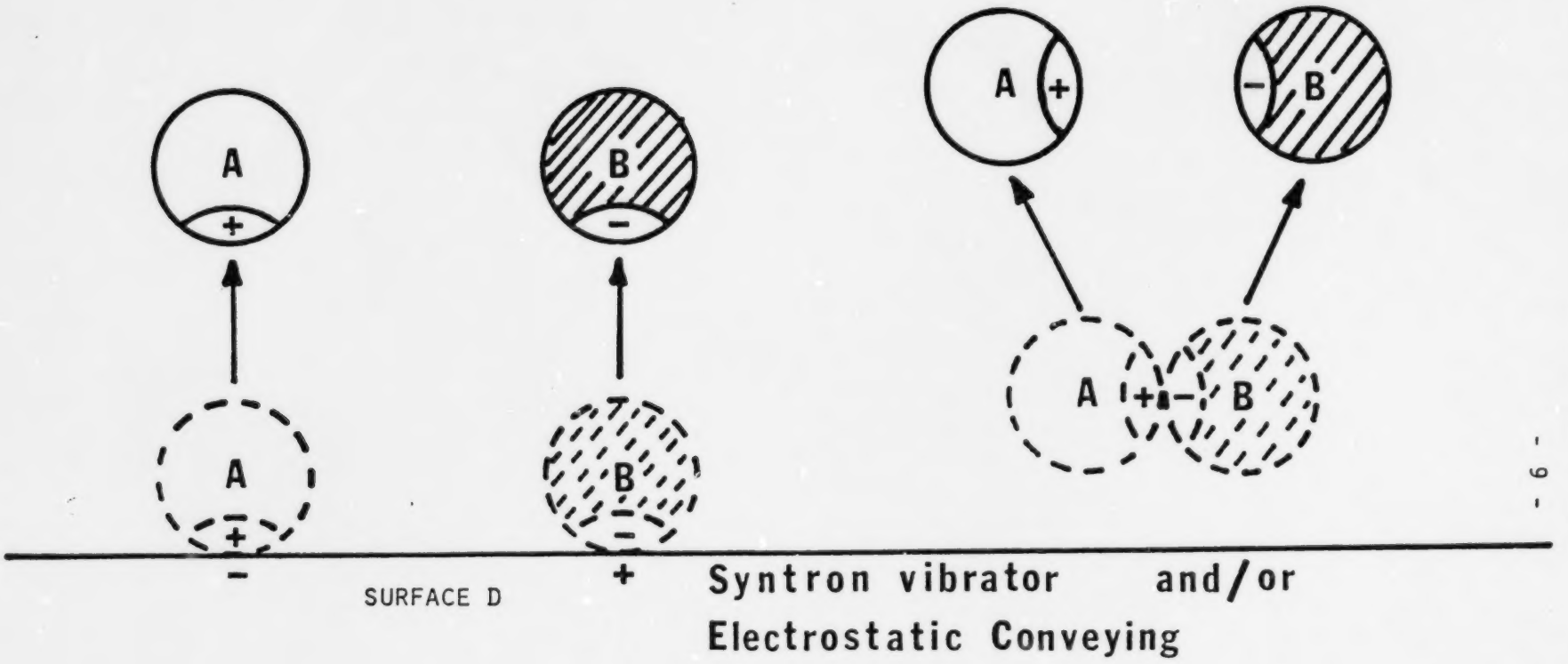


FIG. 4. TRIBOELECTRIFICATION BETWEEN PARTICLES A AND B AND SURFACE D

B. OBJECTIVES

The beneficiation objectives for this project have been set by DSS (EMR) in consultation with B.C. Hydro to reduce the mineral matter content to less than 25% ash (20% moisture basis) or 30% (by weight, dry base) while retaining 90% of the raw coal calorific values. The process should be capable of expanding and beneficiating varying amounts of coal, depending on the raw material mix obtained during a particular period of mining. While the ultimate coal burning rate may reach as high as 40,000 ton/day, it is expected that the fraction which will require beneficiation will be substantially smaller.

C. TEST COALS

The coal was supplied by B.C. Hydro in two different batches:

a 2-ton batch (#1) with 48% average mineral matter content

a 400-lb batch (#2) with 43.5% average mineral matter content.

The majority of the tests were performed with the larger batch (#1) which was received at the beginning of the project. The smaller, second batch, purposely requested with lower mineral matter content, was received at a later date and was used mainly for tests which will enable some comparison with the beneficiation efficiencies obtained by washing.

i) Batch #1

It is understood that the ten barrels of test coal supplied by B.C. Hydro came from a surface trench located well above the regional

ground water level. Significant signs of natural oxidation and other alteration noted in the coal are, therefore, not surprising.

It is further understood that the coal samples are Zone B material from a near surface limb of the basin-shaped deposit. In the previous discussion, the Zone B coal described came from deep boreholes assumed to be in the centre of the basin. The ash fraction of the test coal used in this electrostatic separation project may differ, therefore, from the mineralogy previously described.

a) Visual Description of Test Coal

A representative sample of the chunky coal supplied by B.C. Hydro was observed in hand specimen and under the binocular microscope. The coal is described as a banded, low grade sub-bituminous coal having a highly variable lustre. Black particles dominated the coal received, so it is presumed that interbed waste materials were essentially absent from the test sample.

The coal consists of a mixture of brilliant, high lustre, black vitrain with a distinctly conchoidal fracture and dull black fusain having a more granular looking texture on the fracture surfaces. Under the microscope, most conchoidal fracture surfaces were markedly stepped in appearance.

Many of the coal fragments were characterized by thin laminations, lenses, pockets, etc. of a wide variety of materials including clayey looking material, coal fragments, clear amber coloured resin and possibly yellow iron sulphides.

The dull, granular looking coal seemed to be easily altered by atmospheric weathering, and surface coatings of yellow alteration

products (probably jarosite) and white gypsum were common. The gypsum existed both as massive coatings to globs and clear selenite crystals. The harder conchoidal surfaces of vitrain were essentially unaffected by this alteration. It is believed that these alteration products reflect a combination of in situ and post-sampling oxidation.

b) Preliminary Mineralogy of Test Coal

The mineralogy of the test coal has been defined by a combination of analyses including ignition, hydrogen peroxide treatment, glycol retention analyses and x-ray diffraction. The heating, ignition and calcining experiments will be described first, followed by the preliminary mineralogy of the non-carbonaceous fraction.

Weight loss - stage heating experiments:

Weight loss versus temperature curves are given in Fig. 5 for the test coal pulverized to < 160 μm. In all cases the 750°C cumulative weight loss* is about 49%. Stepwise heating yielded weight loss values at a variety of temperatures as shown by the curves on the figure. It is clear that these heating procedures yield variable weight loss data over a large, poorly defined temperature range between 150 and 450°C.

In all of the measurements plotted on Fig. 5, the hot samples were cooled in a desiccator prior to weighing to prevent rehydration from the atmosphere. One series of weight loss experiments was run without the above controls, and during cooling in open dishes a significant rehydration took place. The cumulative error produced is shown by the upper curve in Fig. 6. This rehydration phenomenon is directly related to the presence of the clay mineral, montmorillonite, in the ash fraction of the coal.

by definition, calcining, heating without air (NRL)
No! To heat without freezing and/or to heat in an oxidizing atmosphere.

*calcination in air

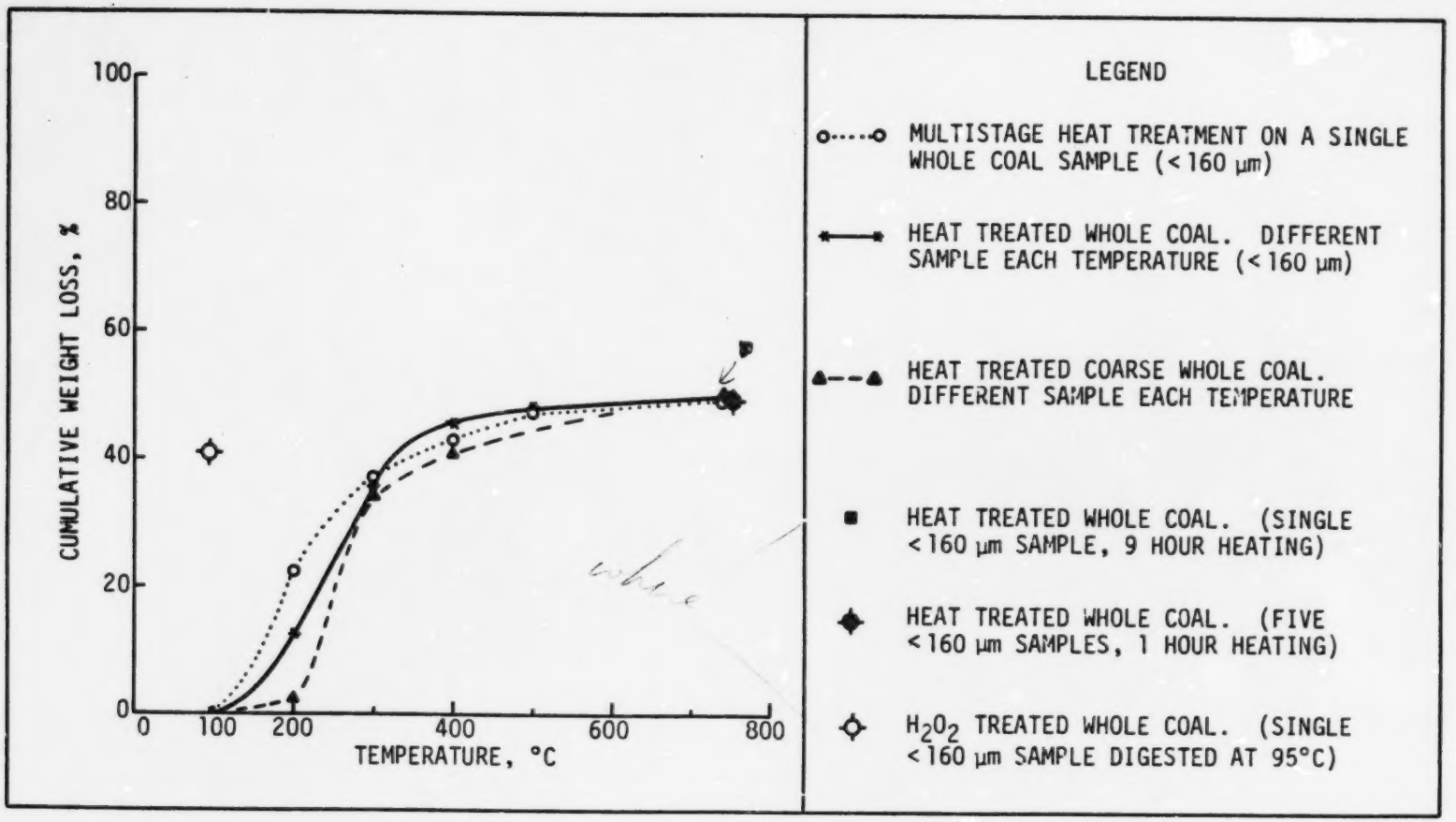

100
80
60
40
20
0
CUMULATIVE WEIGHT LOSS, %
0
100
200
400
600
800
TEMPERATURE, °C
LEGEND
MULTISTAGE HEAT TREATMENT ON A SINGLE WHOLE COAL SAMPLE (< 160 µm)
HEAT TREATED WHOLE COAL. DIFFERENT SAMPLE EACH TEMPERATURE (< 160 µm)
HEAT TREATED COARSE WHOLE COAL. DIFFERENT SAMPLE EACH TEMPERATURE
HEAT TREATED WHOLE COAL. (SINGLE < 160 µm SAMPLE, 9 HOUR HEATING)
HEAT TREATED WHOLE COAL. (FIVE < 160 µm SAMPLES, 1 HOUR HEATING)
H_2O_2 TREATED WHOLE COAL. (SINGLE < 160 µm SAMPLE DIGESTED AT 95°C)

FIGURE 5. WEIGHT LOSS PRODUCED BY H_2O_2 DIGESTION AND BY STAGE HEATING OF COAL SAMPLES TO 750°C

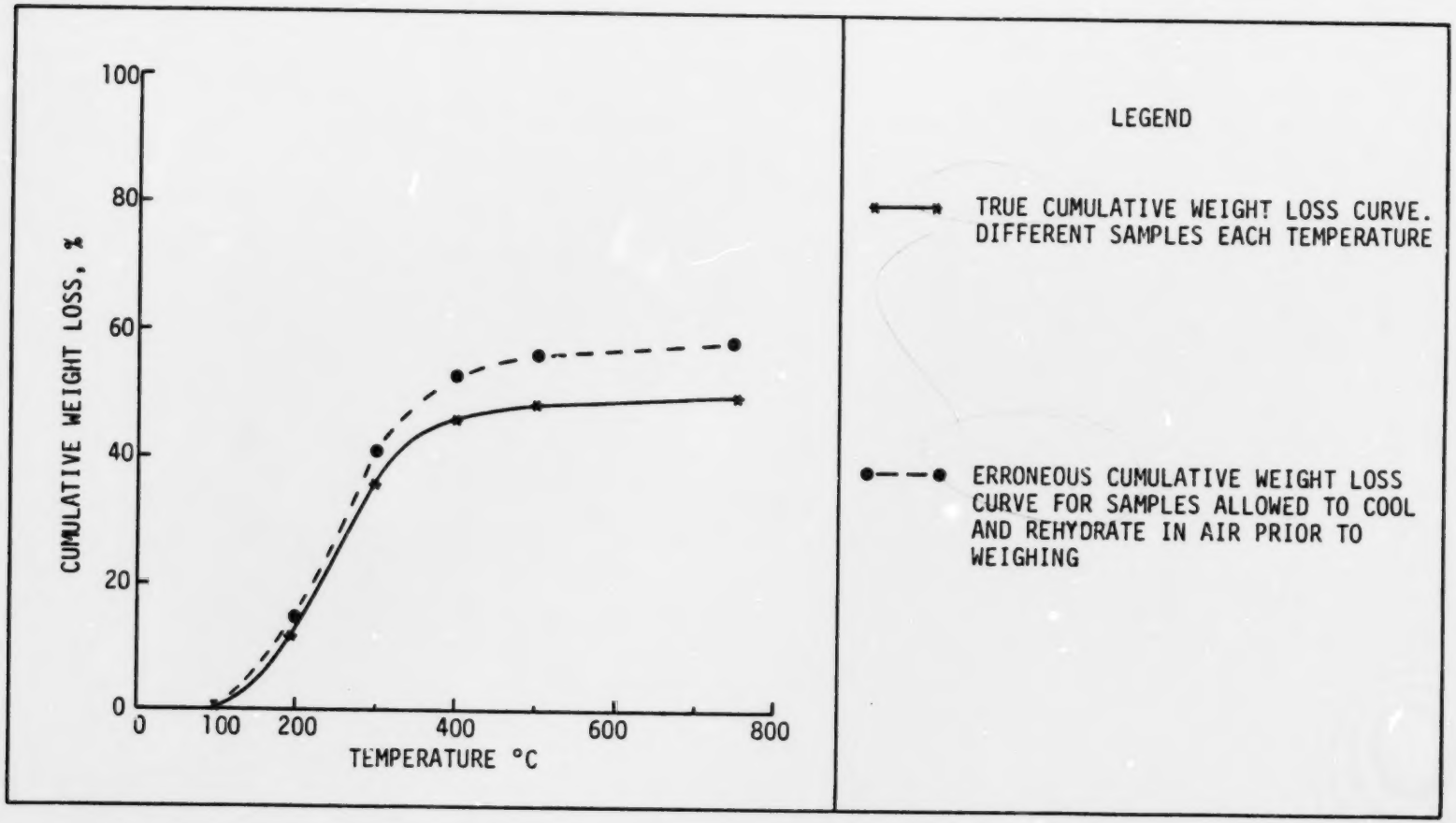


FIGURE 6 . ERRONEOUS AND TRUE WEIGHT LOSS VS TEMPERATURE CURVES
(< 160 µm SIZE FRACTION, SEE LEGEND FOR PROCEDURES)

In an attempt to assess how much of the weight loss was actually caused by burning of the coal, a sample was digested for several days in hot H_2O_2 until oxidation terminated. The weight loss associated with this type of low temperature oxidation was 41% compared with 49% by 750°C burning.

When clay minerals are subjected to high temperatures they lose adsorbed and structural water as shown in Fig. 7. The two principal clay minerals in the residue of the Hat Creek coal are montmorillonite and kaolinite. At 750°C these minerals lose water amounting, respectively, to about 8% and 14% of their weight.

Using the mineralogical composition established for the test coal below, a cumulative weight loss of about 4.1% may be attributed to clay mineral dehydration at the final oven temperature of 750°C.

Mineralogy of the non-organic fraction of the coal:

X-ray powder patterns obtained on the heated samples discussed in the previous section are shown in Fig. 8. The 7 Å kaolinite peak is diminished but remains intact up to 450°C then is completely destroyed by heating at 500°C. The 15 to 20 Å peaks of the contained smectites remain visible, probably by atmospheric rehydration, up to temperatures of 300°C. At 400°C and above, the smectites remain permanently collapsed. The 4.5 Å hk0 peaks remain visible on all traces despite removal of crystal lattice hydroxyls.

X-ray diffraction traces of oriented < 2 μm specimens of the heated residues are shown in Fig. 9. Again the effect of heat treatment on the strength of the (001) peaks of kaolinite and montmorillonite is apparent.

The residue left following H_2O_2 treatment of the bulk coal was

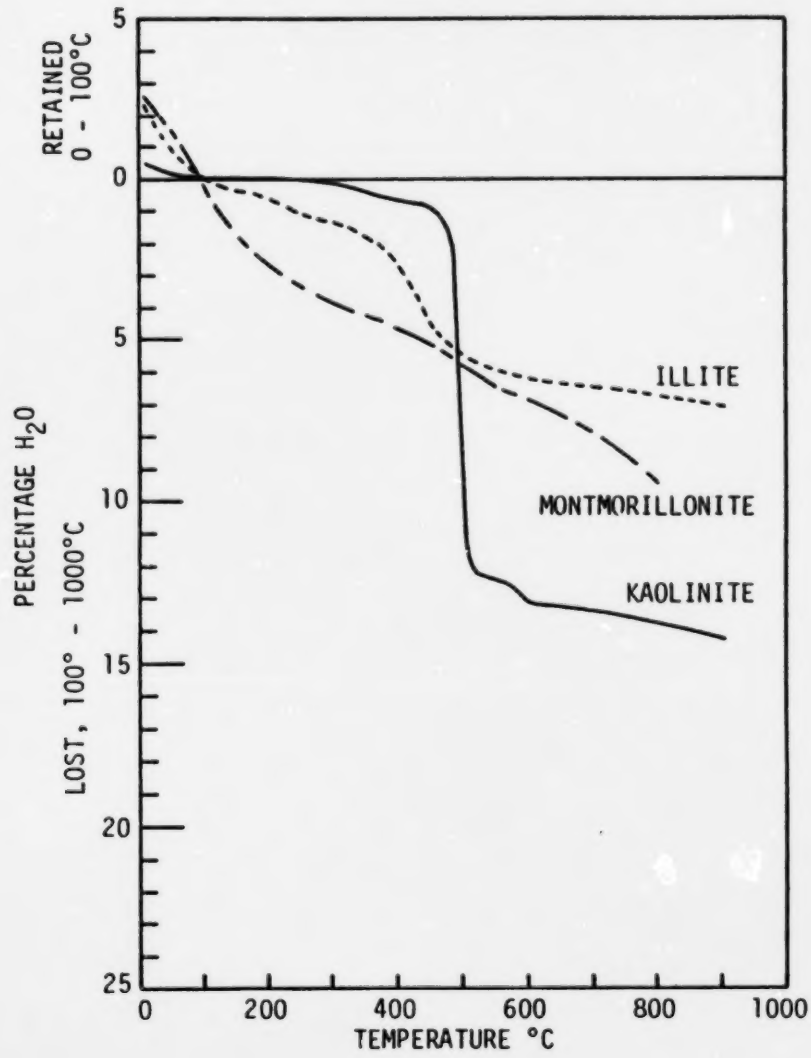


FIGURE 7. TYPICAL DEHYDRATION CURVES OF SELECTED CLAY MINERALS [Adapted from Jackson, 1956]

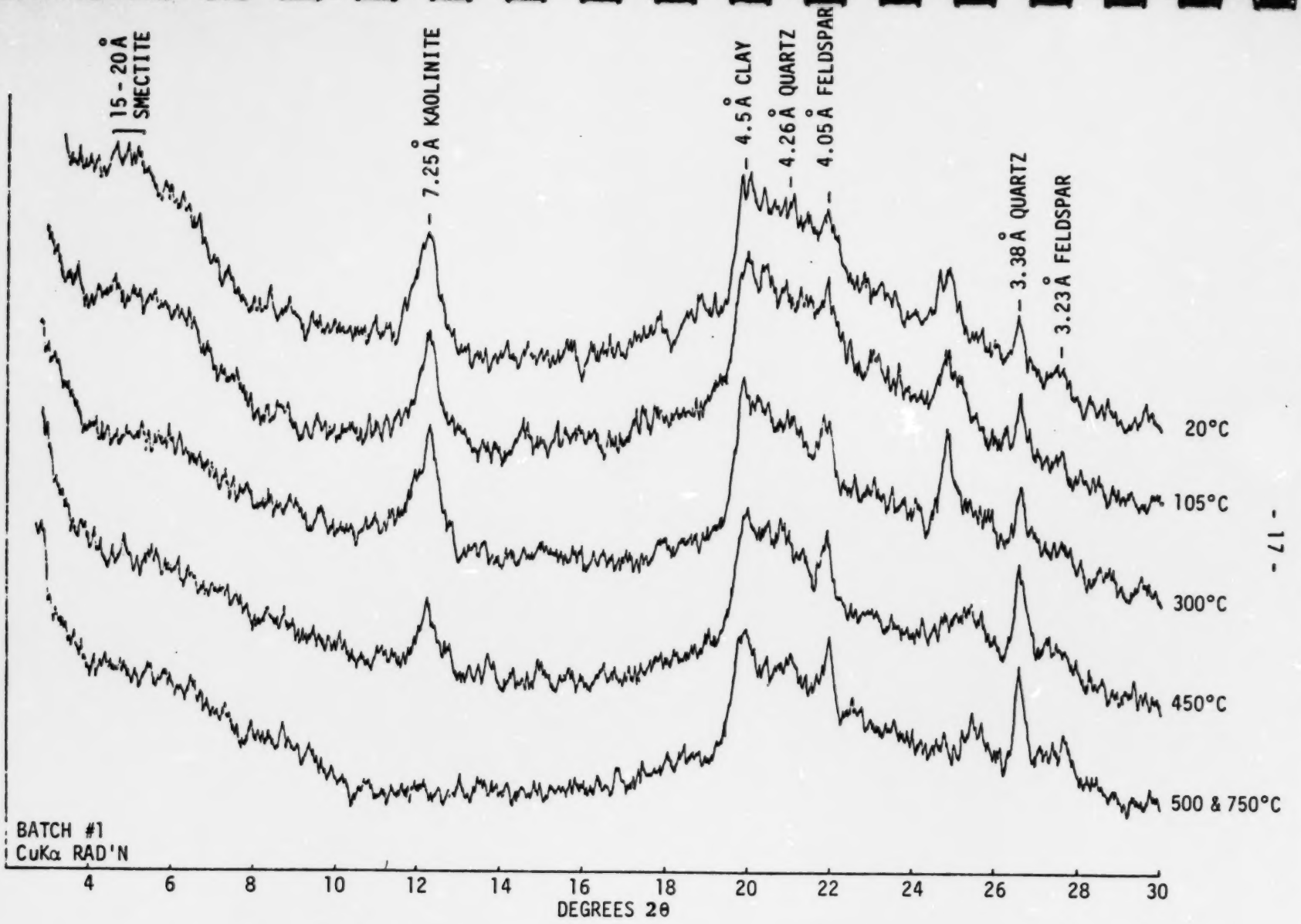


FIGURE 8. X-RAY POWDER PATTERNS OF COAL HEATED FROM 20°C TO 750°C SHOWING PROGRESSIVE DESTRUCTION OF CLAY MINERALS IN THE RESIDUE

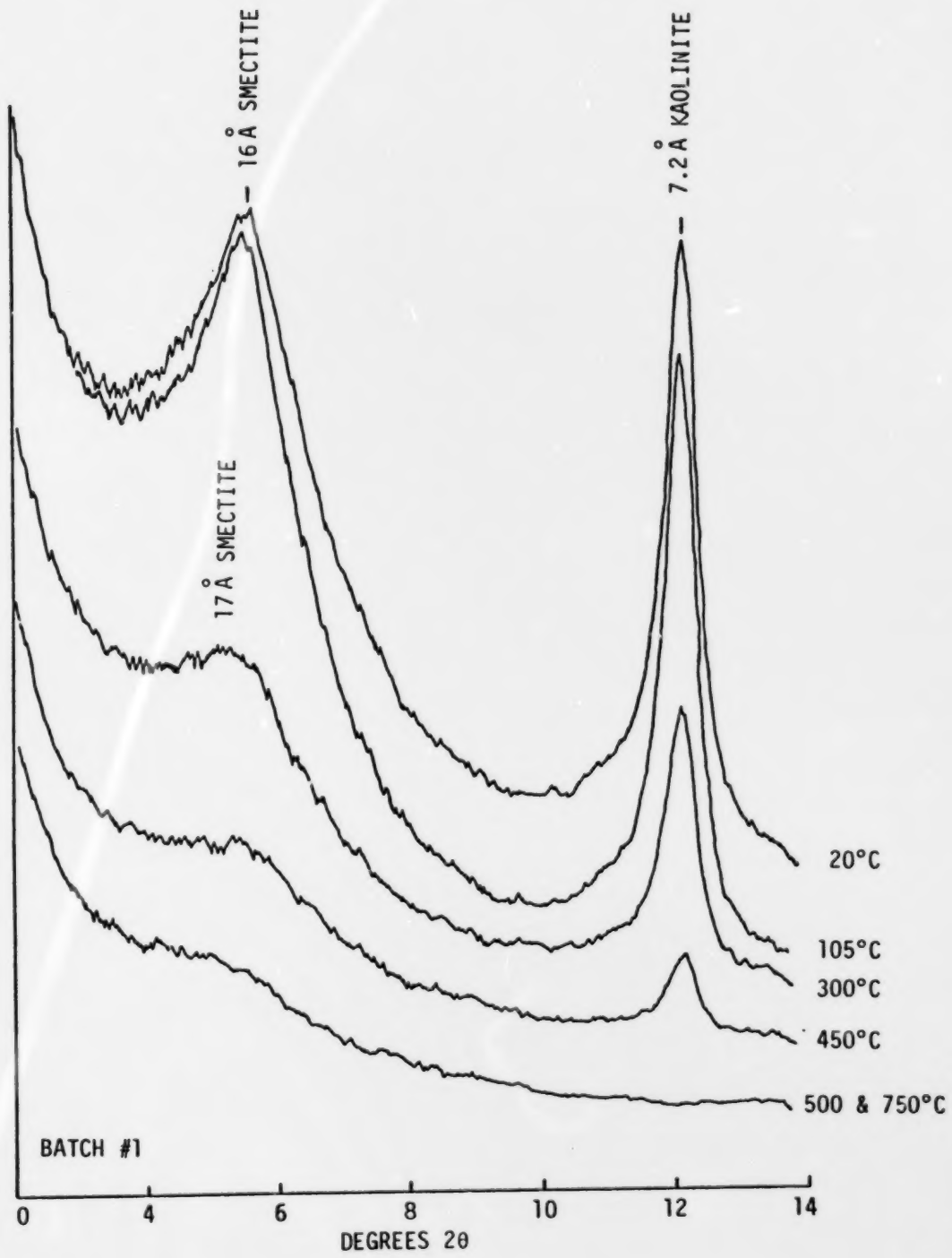


FIGURE 9. X-RAY DIFFRACTION TRACES OF ORIENTED SPECIMENS OF < 2 μm ASH RESIDUE FROM WEIGHT LOSS TESTS HEATED AS SHOWN (CuKα RADIATION)

analyzed for its mineralogical composition. Since the residue had not been heated, the clay minerals were not altered by drying and calcining as discussed previously. The x-ray traces run on the residue (Fig. 33, p.69, trace b) showed the presence of montmorillonite, kaolinite, quartz, some feldspar and possibly some cristobalite.

Preliminary glycol retentions run on the residue yielded an average value of about 115 mg/g which indicates a montmorillonite content of 30 to 35% of the ash. Using x-ray peak height ratio techniques for the non-smectite components, the ash fraction is estimated to have the following approximate composition:

Non-combustible residue

Montmorillonite	30 - 35%
Kaolinite	~ 30%
Quartz and cristobalite	~ 30%
Feldspar	~ 5%

If the coal content is assumed to be 41% as determined by the H_2O_2 treatment, then the test coal is estimated to have the following approximate composition:

Test coal

Coal and other organics	~ 41%
Montmorillonite	~ 20%
Kaolinite	~ 18%
Quartz and cristobalite	~ 18%
Feldspar	~ 3%

ii) Batch #2

X-ray powder patterns obtained on the whole coal and the residue from the whole coal are shown as traces (a) and (b) on Fig. 10. The patterns indicate the presence of abundant montmorillonite, kaolinite

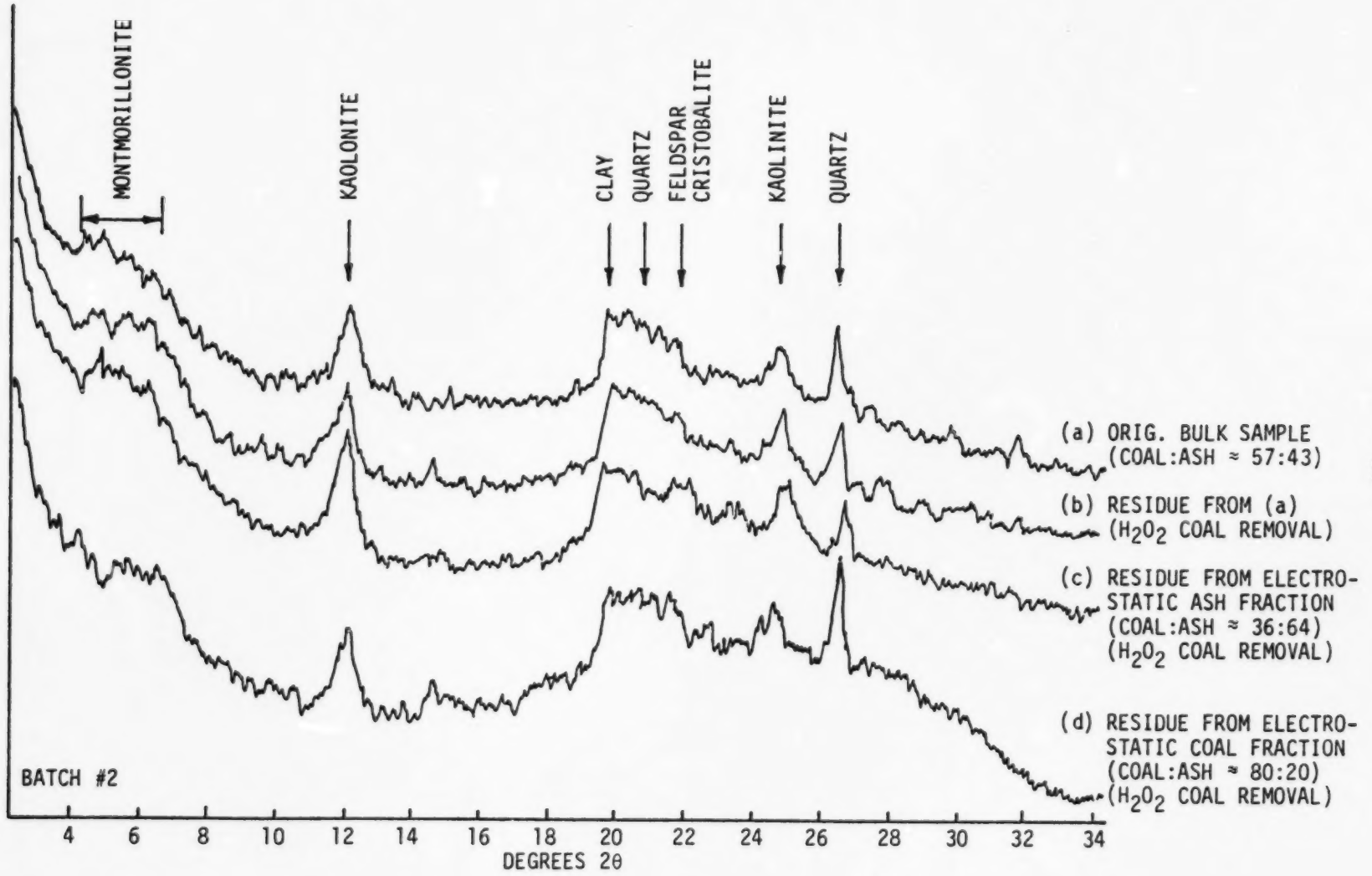

MONTMORILLONITE
KAOLONITE
CLAY
QUARTZ
FELDSPAR
CRISTOBALITE
KAOLINITE
QUARTZ
(a) ORIG. BULK SAMPLE (COAL:ASH ≈ 57:43)
(b) RESIDUE FROM (a) (H_2O_2 COAL REMOVAL)
(c) RESIDUE FROM ELECTRO-STATIC ASH FRACTION (COAL:ASH ≈ 36:64) (H_2O_2 COAL REMOVAL)
(d) RESIDUE FROM ELECTRO-STATIC COAL FRACTION (COAL:ASH ≈ 80:20) (H_2O_2 COAL REMOVAL)
BATCH #2
4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
DEGREES 2θ

FIGURE 10. X-RAY POWDER PATTERNS OF HAT CREEK BATCH #2 COAL SAMPLES WITH COAL:ASH = 57:43, CuKα RADIATION

and quartz with some feldspar/cristobalite. The traces are very similar to those obtained from Batch #1 except that quartz may be more abundant and the smectite appears better ordered.

An oriented trace of the < 2 μm fraction of the residue from the Batch #2 coal is shown in Fig. 11. Kaolinite and montmorillonite dominate the residue along with a significant amount of what appears to be interlayered clay mineral yielding the 5.94 Å peak.

Glycol retention analyses were run on three residues of Batch #2 coal as shown in Fig. 12. Also plotted is a single result from Batch #1.

The glycol retention value of 84 mg/g obtained on the residue from the Batch #2 bulk sample is significantly below the value of 115 mg/g obtained for Batch #1. This reflects a decrease in specific surface indicating less montmorillonite in Batch #2 than Batch #1. Other contained minerals such as kaolinite and quartz should be correspondingly more abundant in Batch #2.

Using the glycol retentions as a direct indicator of smectite content, the percentage montmorillonite in the Batch #2 residues is given below along with a rough estimate of quartz and kaolinite using peak height ratios.

Mineral	Batch #1 Residue	Batch #2 Residue		
	Bulk	Bulk	64% Ash	20% Ash
Montmorillonite	~ 37	~ 27	~ 31	~ 23
Kaolinite	~ 30		45-50	35-40
Quartz and cristobalite	~ 30		20-25	35-40
Feldspar	~ 5	Tr	Tr	Tr

Tr = trace

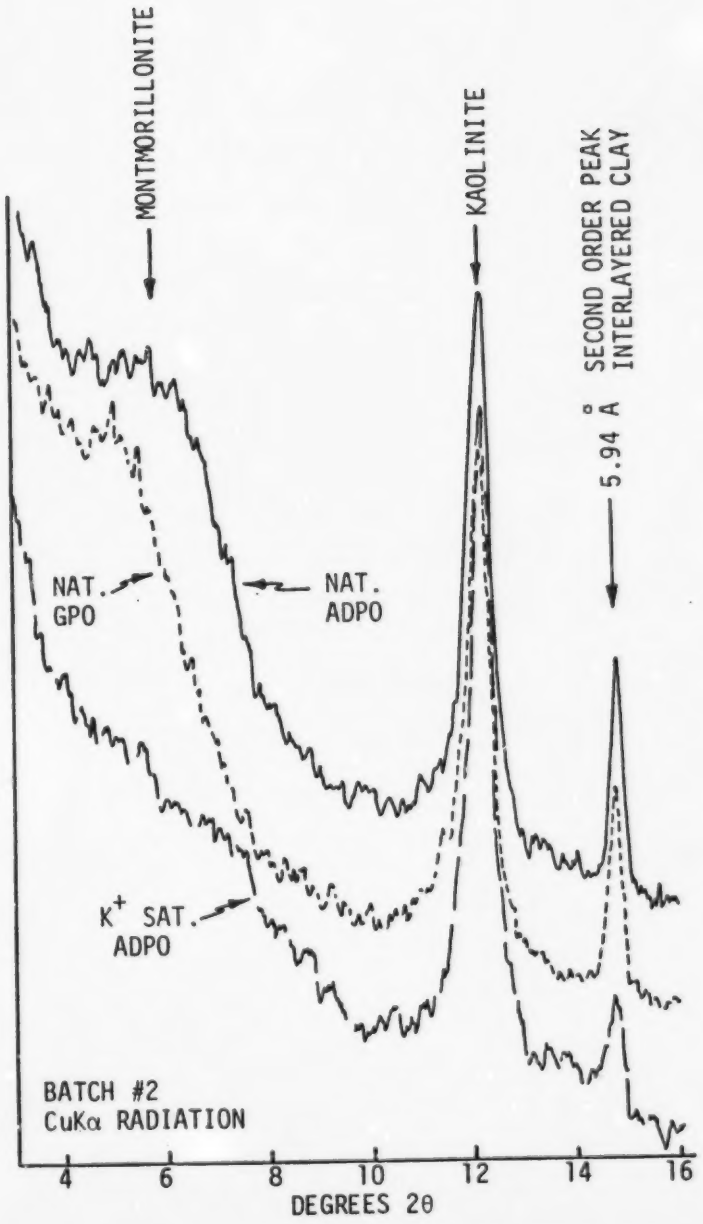


FIGURE 11. X-RAY DIFFRACTION TRACES OF <2 μm FRACTION OF RESIDUE FROM BATCH #2 BULK COAL SAMPLE (COAL:ASH = 57:43): NATURAL AND K^+ SATURATED: COAL REMOVED BY H_2O_2 DIGESTION

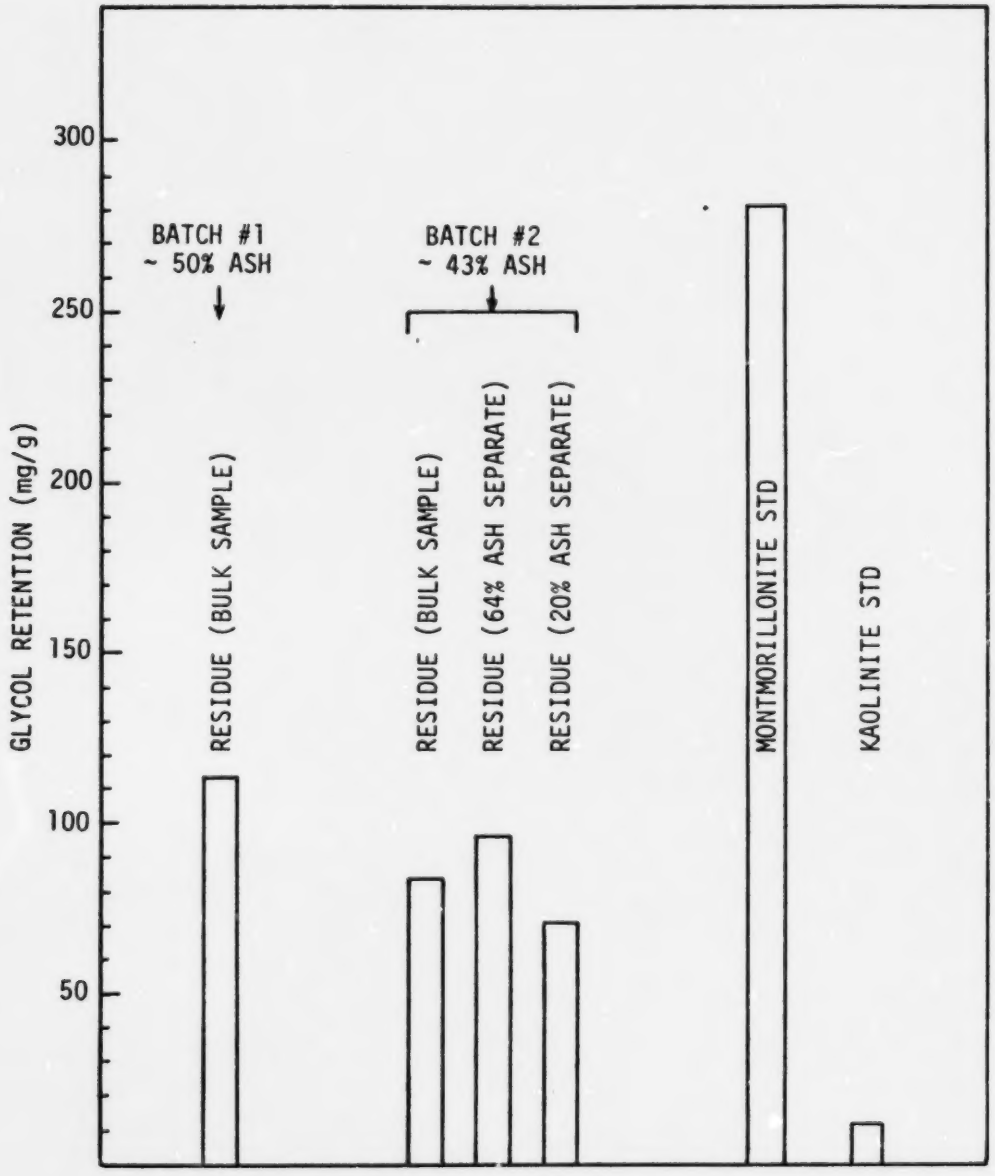


FIGURE 12. GLYCOL RETENTION VALUES FOR RESIDUE OF H_2O_2 TREATED SAMPLES AS SHOWN

iii) Material Preparation

For the Batch #1 coal, in order to prepare samples of consistent characteristics to be used throughout the project, eight drums of the material containing approximately 400 lb of coal each were re-mixed according to the steps shown in Photographs 1, 2 and 3.

By adopting the coning, sectioning and re-mixing procedure, all samples used in the experiments were representative of the entire 2-ton batch sent to us by B.C. Hydro.

D. APPARATUS AND OPERATION

At the basis of the process is the fluidized bed triboelectrification (Ref. 2) combined with gravity feeding. Through its multiple collisions, the fluidization produces individualized charged particles. By allowing such particles to flow out of the bed, while in suspension in the fluidizing gas, they retain the selective tribo charge and thus become amenable to separation by a horizontal electrostatic field.

It is expected that the final pilot installation will be a multi-cell concept with a fluidized bed feeder (see Figs.37 and 38, p.79 and 80). The raw coal will be fed to a common fluidized bed from where the material will fall through the separation cells. The large walls of each cell will be connected in sequence to a ground and high voltage potential. Assuming that the coal-rich fraction particles triboelectrify positively (and, implicitly, that the mineral matter-rich particles triboelectrify negatively), the positive particles will be deflected in the direction of the electric field established in each cell and the negative particles

STEPS IN THE PREPARATION OF THE HAT CREEK COAL BATCHES TO BE USED THROUGHOUT THE PROJECT - CONTRACT NO. ISU78-00122

PHOTO 1
Coning of the two tons of Hat Creek coal received from B.C. Hydro

PHOTO 2
Sectioning of the cones in eight

PHOTO 3
Mixing the sections (one from each cone) in eight drums

in the opposite direction.

If necessary, the stream with the mineral matter-rich fractions could be collected and sent to a second stage separator for further beneficiation.

Fig. 13 shows the cell used in the experiments. Beginning at the top, it comprises four elements: the vibratory conveyor, the fluidized bed feeder, the separation cell with the electrodes, and the collection trays. The vibratory conveyor is provided with a container to hold the batch of coal to be processed. The fluidized bed feeder is built with walls made out of copper to be triboelectrically compatible with the processing of coal (Ref. 3). It has a 2 x 30 cm^2 slit provided with a butterfly valve to regulate the flow of the fluidized and triboelectrified material. The 2 x 30 cm^2 rectangular slot in the fluidized bed is capable of feeding up to 100 g/s of triboelectrified coal. The separation cell, approximately 1 x 1 m cross section and 3.5 m tall, is completely enclosed allowing for experiments in controlled atmospheres. The collection trays are V shaped and mounted on teflon insulators in a second V-shaped tray, electrically grounded. The twelve trays form the analog of a mass spectrograph.

The fluidization gas is a synthetic mixture of flue gas (nitrogen and carbon dioxide).

The operation of the cell begins by putting a first batch of coal in the fluidized bed feeder so that the expanded fluidized mass will barely reach the level of the butterfly valve, and a measured second batch on the vibratory conveyor. The high voltage is applied to the cell wall, the vibratory conveyor started, and the butterfly valve opened for the specified collection period.

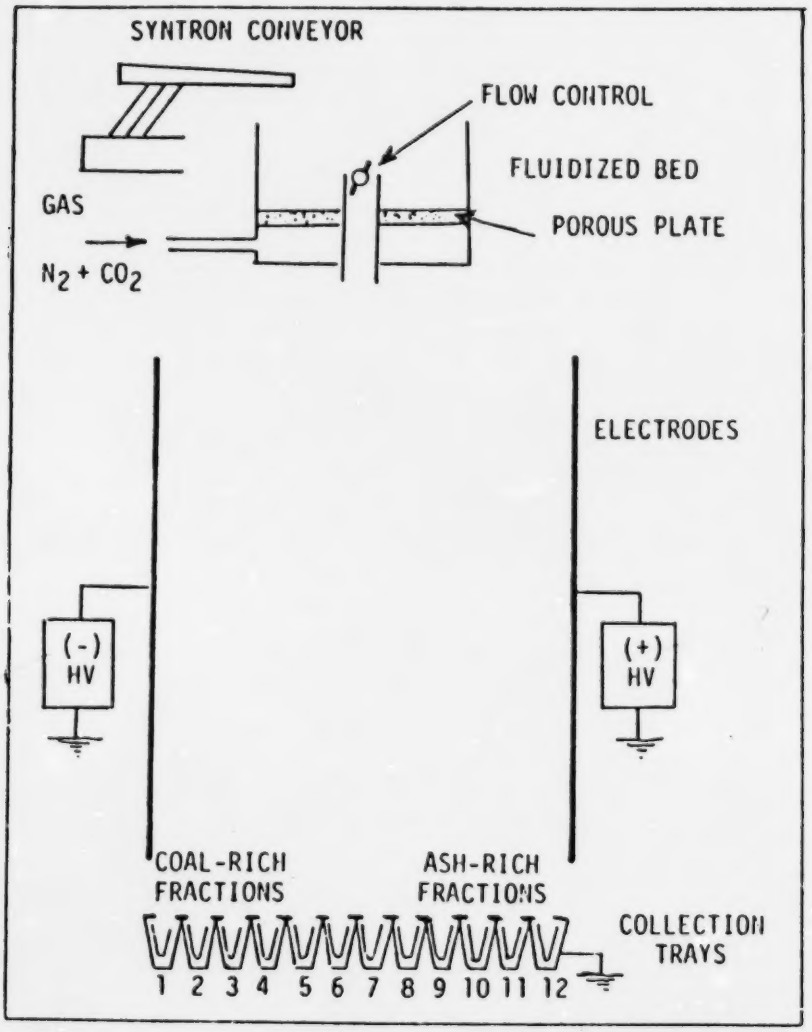


FIGURE 13. EXPERIMENTAL CELL

The material collected in the twelve trays was individually weighed and analyzed. The particles which deposited on the cell walls were brushed down into the adjacent trays, #1 and #12.

E. BENEFICIATION TESTS

i) Selection of Particle Size and Fluidization Velocities

a) Grinding and Sieving Analyses

The particle size distributions for the experimental batches prepared with the apparatus developed at The University of Western Ontario for simultaneous grinding and sieving of coal (Ref. 4) are shown in Fig. 14 for the 100 mesh screen, Fig. 15 for the 50 mesh screen, and Fig. 16 for the 30 mesh screen. The figures show the particle "diameter" against the percentage cumulative weight.

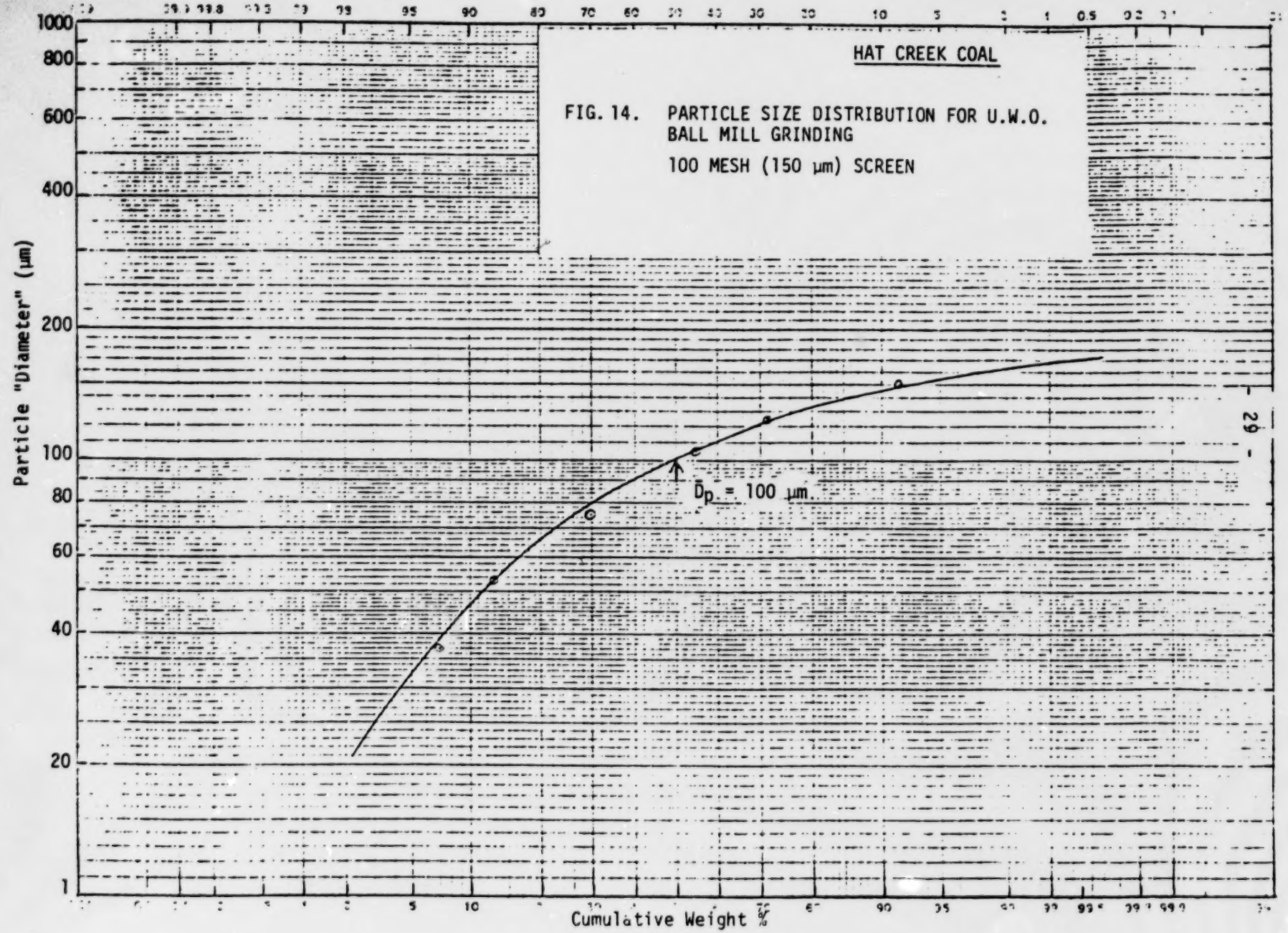
As seen from the figures:

- with the 100 mesh screen, 50% of the material weight is less than 100 μm size
- with the 50 mesh screen, the corresponding size is 160 μm
- with the 30 mesh screen, the corresponding size is 250 μm.

b) Float-sink Beneficiation

In a physical process such as electrostatic beneficiation, the primary consideration in the choice of the particle size is the degree of liberation that can be achieved for the component to be extracted.

As a preliminary investigation, coal and ash recoveries were determined by float-sink analyses for various particle size ranges as


HAT CREEK COAL
FIG. 14. PARTICLE SIZE DISTRIBUTION FOR U.W.O. BALL MILL GRINDING
100 MESH (150 µm) SCREEN
Particle "Diameter" (µm)
1000
800
600
400
200
100
80
60
40
20
1
$\bar{D}_p$ = 100 µm.
Cumulative Weight %
- 29 -

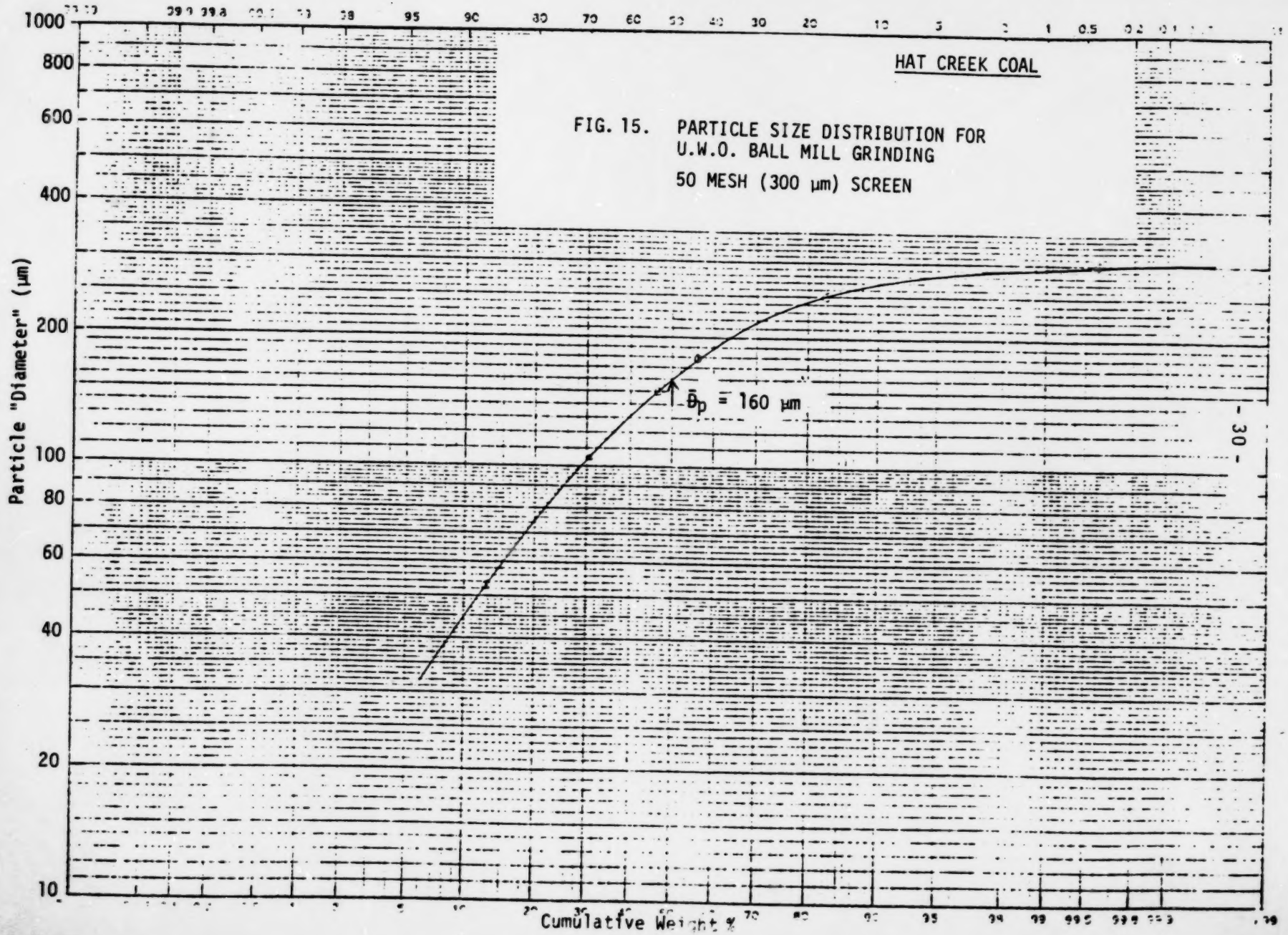
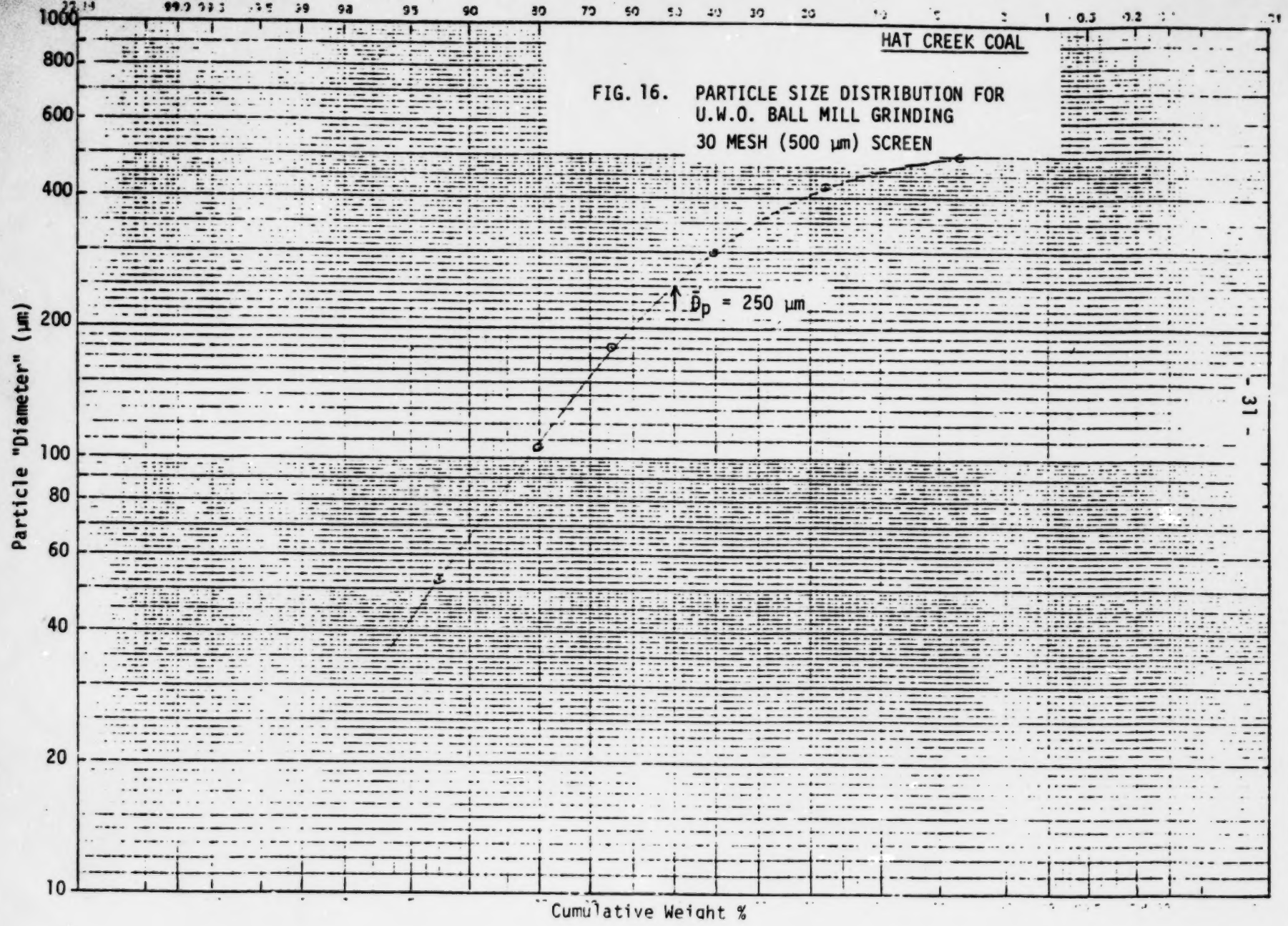


FIG. 15. PARTICLE SIZE DISTRIBUTION FOR U.W.O. BALL MILL GRINDING
50 MESH (300 µm) SCREEN


HAT CREEK COAL
FIG. 16. PARTICLE SIZE DISTRIBUTION FOR U.W.O. BALL MILL GRINDING
30 MESH (500 µm) SCREEN
$\bar{D}_p$ = 250 µm
Particle "Diameter" (µm)
1000
800
600
400
200
100
80
60
40
20
10
Cumulative Weight %

shown in Table I.

While such tests are normally applied to larger particle sizes, and as such they may not be fully representative of the actual recoveries which could be obtained, they have been deemed to be a useful preliminary study of the Hat Creek coal.

c) Fluidization Velocities

As it is planned to achieve triboelectrification through fluidization of the material, experiments have been carried out to determine the minimum fluidization velocities for the materials produced with the 100, 50 and 30 mesh screens. The results are shown in Figs. 17, 18 and 19, where the pressure drop in the bed is plotted against the superficial velocity of the fluidizing gas.

[In a fluidized bed, if the gas flow rate is gradually increased, a critical value is reached where the drag of the gas on the particles is equal to their weight. The superficial velocity at which this takes place is called the minimum fluidization velocity or V_{mf}.]

d) Electrostatic Beneficiation Tests with Various Particle Sizes in Synthetic Flue Gas

The first series of tests was focused on finding the beneficiation that could be achieved with various particle sizes. Three ranges of particles were chosen: < 500 μm, < 300 μm, and < 150 μm. [The last particle size range could be directly used in boilers in power plants.]

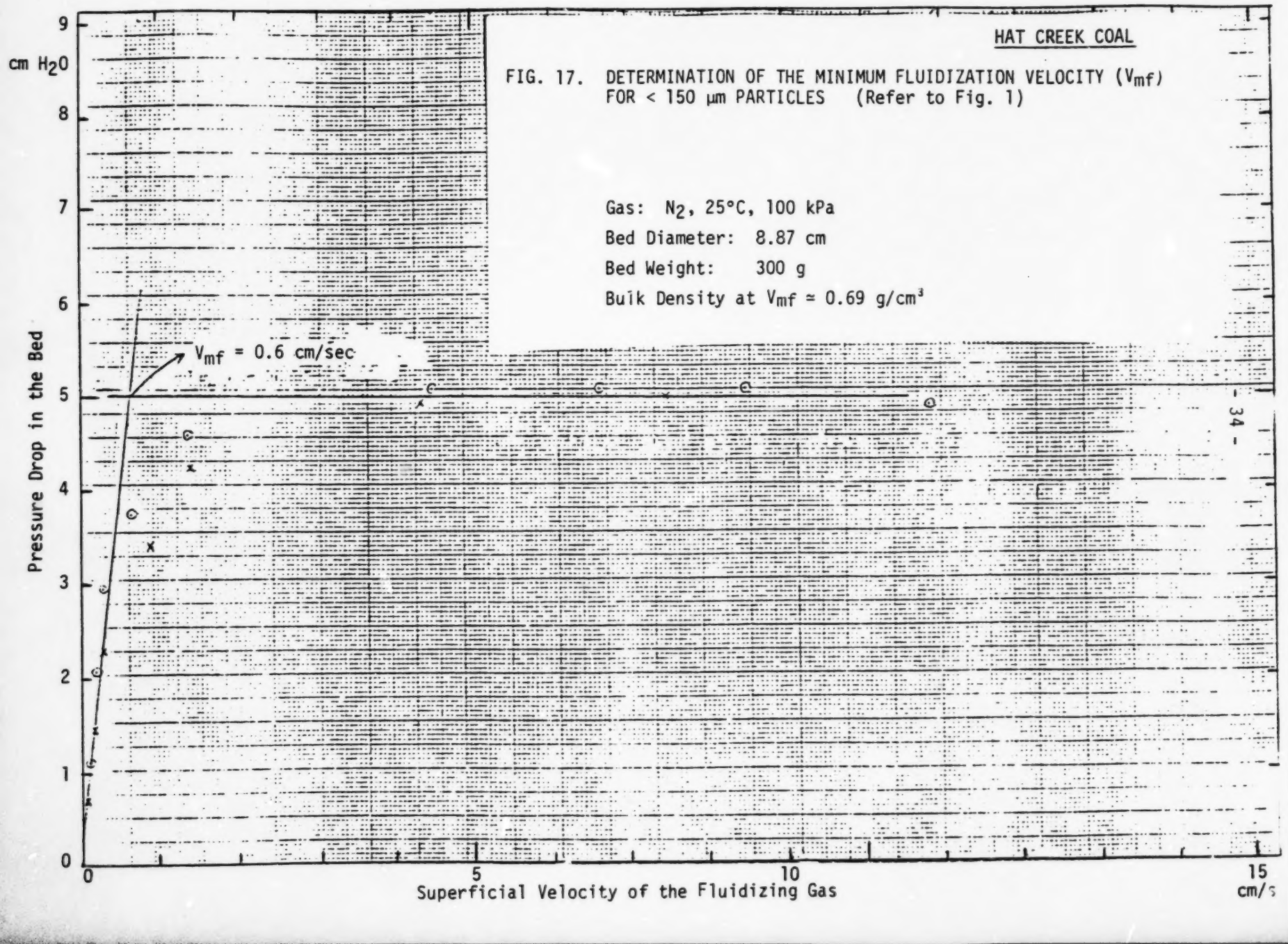
The results are shown in Figs. 20, 21 and 22. [For the preliminary evaluation tests, in order to minimize possible bouncing-off effects for some of the more conductive particles, the value of the electric field intensities used for the horizontal separation was chosen below 1 kV/cm.

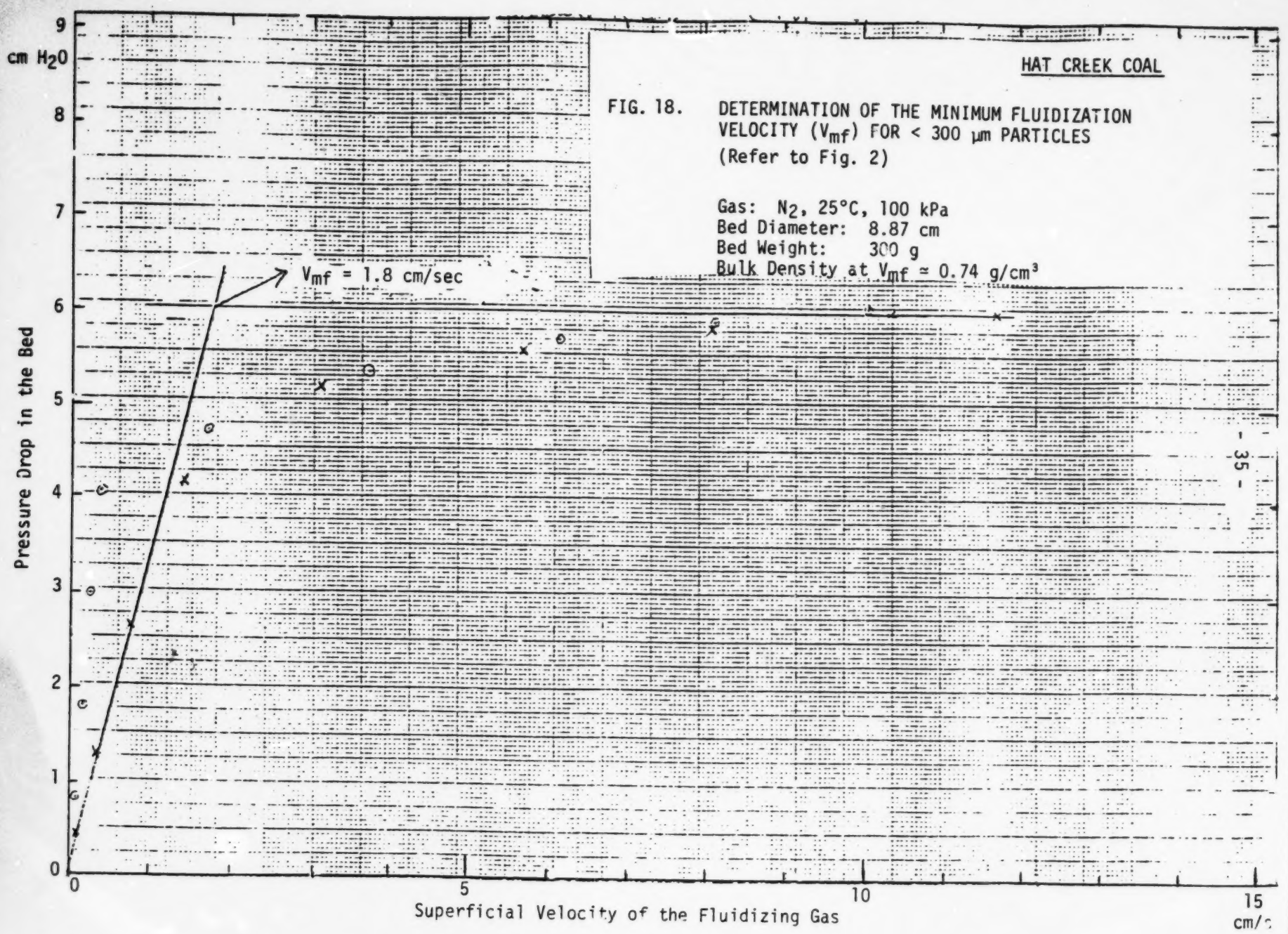
TABLE I. FLOAT SINK ANALYSES - HAT CREEK COAL

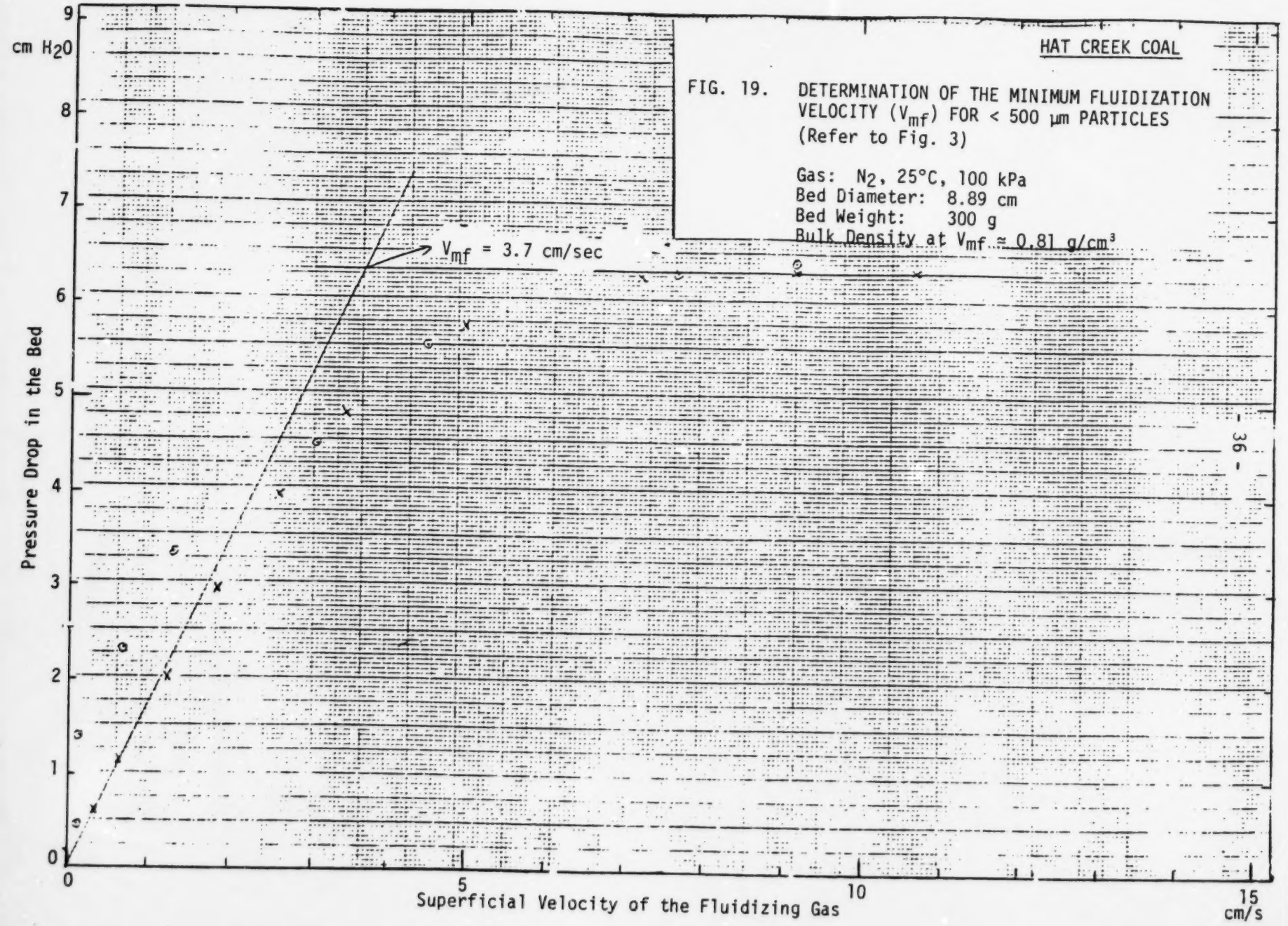
Particle size range (μm)	Average particle size $\bar{D}_p$ (μm)	Coal in Float				Ash in Sink			
		Coal content in original batch (a)	Float fraction (b)	Coal content in float (c)	Coal recovery from float (b x c / a)	Ash content in original batch (a')	Sink fraction (b')	Ash content in sink (c')	Ash recovery from sink (b' x c'/a')
< 500 μm	250 μm	0.5268 0.5251	0.6600 0.6441	0.6903 0.6947	0.8648 0.8521	0.4732 0.4749	0.3400 0.3559	0.7905 0.7818	0.5680 0.5858
< 300 μm	160 μm	0.5191 0.5138	0.6620 0.6417	0.6833 0.6898	0.8714 0.8615	0.4809 0.4862	0.3380 0.3583	0.8025 0.8013	0.5640 0.5905
< 150 μm	100 μm	0.5205 0.5062	0.6155 0.5873	0.7179 0.7252	0.8489 0.8414	0.4795 0.4938	0.3845 0.4127	0.7956 0.8054	0.6380 0.6731
425 - 500 μm (from < 500 μm batch)	465 μm	0.5061	0.6560	0.6815	0.8834	0.4939	0.3440	0.8284	0.5770
106 - 150 μm (from < 300 μm batch)	130 μm	0.5049	0.6458	0.6735	0.8615	0.4951	0.3542	0.8024	0.5740
53 - 106 μm (from < 300 μm batch)	80 μm	0.4931	0.6167	0.6774	0.8472	0.5069	0.3833	0.8035	0.6076
0 - 53 μm (from < 150 μm batch)	30 μm	0.4932	0.6450	0.6582	0.8608	0.5068	0.3550	0.8065	0.5649

Notes: (i) Float - Sink medium: Ethylene Bromide (Sp. Gravity: 2.17)

(ii) Coal and ash contents are calculated on a dry basis.


HAT CREEK COAL
FIG. 17. DETERMINATION OF THE MINIMUM FLUIDIZATION VELOCITY (V_{mf}) FOR < 150 μm PARTICLES (Refer to Fig. 1)
Gas: N_2, 25°C, 100 kPa
Bed Diameter: 8.87 cm
Bed Weight: 300 g
Bulk Density at V_{mf} ≈ 0.69 g/cm³
V_{mf} = 0.6 cm/sec
cm H_2O
Pressure Drop in the Bed
Superficial Velocity of the Fluidizing Gas
cm/s
0
1
2
3
4
5
6
7
8
9
0
5
10
15


HAT CREEK COAL
FIG. 18. DETERMINATION OF THE MINIMUM FLUIDIZATION VELOCITY (V_{mf}) FOR < 300 μm PARTICLES
(Refer to Fig. 2)
Gas: N_2, 25°C, 100 kPa
Bed Diameter: 8.87 cm
Bed Weight: 300 g
Bulk Density at V_{mf} ≈ 0.74 g/cm³
V_{mf} = 1.8 cm/sec
cm H_2O
Pressure Drop in the Bed
Superficial Velocity of the Fluidizing Gas
cm/s
0
1
2
3
4
5
6
7
8
9
0
5
10
15


HAT CREEK COAL
FIG. 19. DETERMINATION OF THE MINIMUM FLUIDIZATION VELOCITY (V_{mf}) FOR < 500 µm PARTICLES
(Refer to Fig. 3)
Gas: N_2, 25°C, 100 kPa
Bed Diameter: 8.89 cm
Bed Weight: 300 g
Bulk Density at V_{mf} ≈ 0.81 g/cm³
V_{mf} = 3.7 cm/sec
cm H_2O
Pressure Drop in the Bed
Superficial Velocity of the Fluidizing Gas
cm/s
0
1
2
3
4
5
6
7
8
9
0
5
10
15

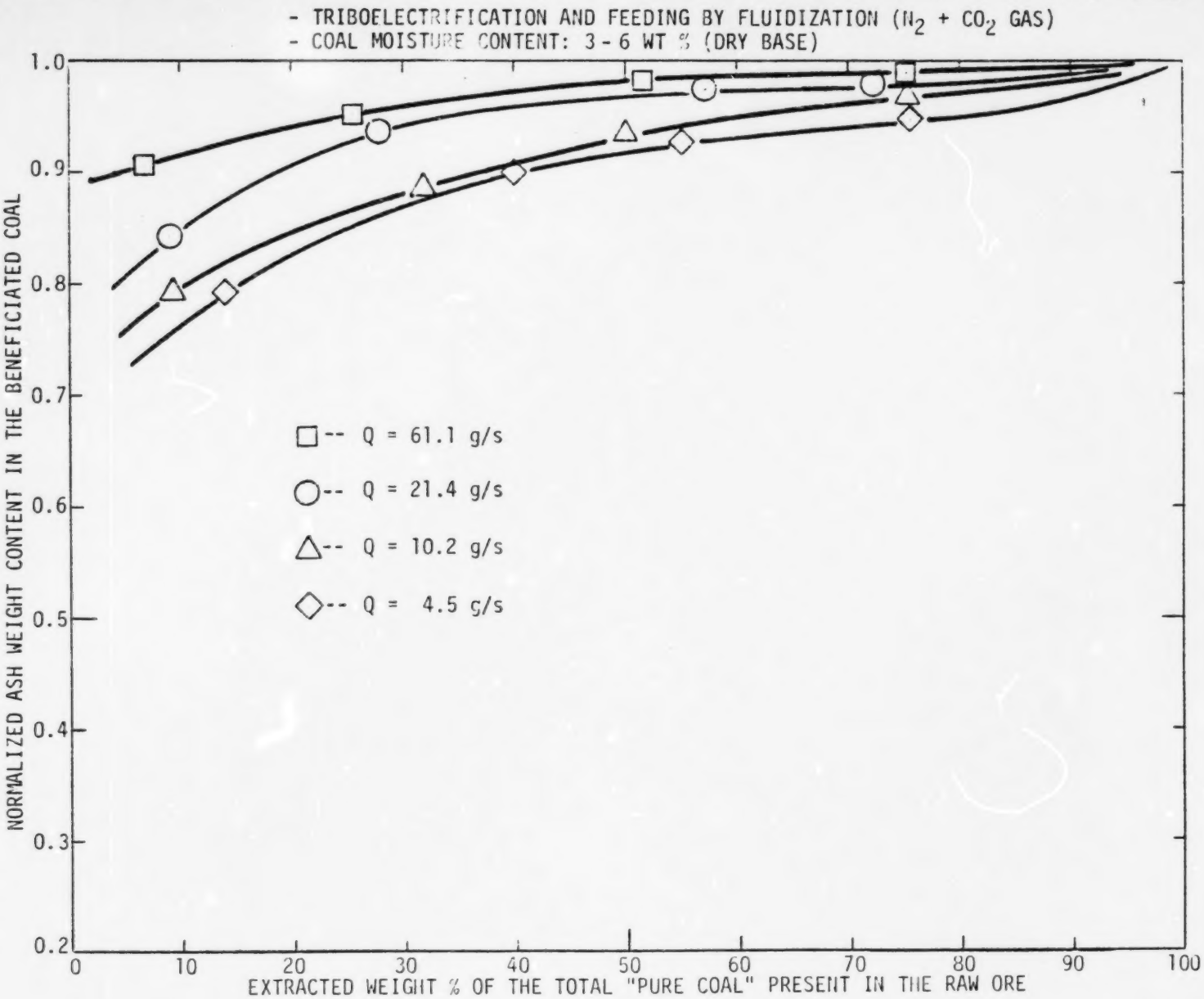


FIGURE 20, ONE-STAGE ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (D_p < 500 μm) AT LOW ELECTRIC FIELDS (E = 0.82 kV/cm) AND VARIOUS RATES OF FEED

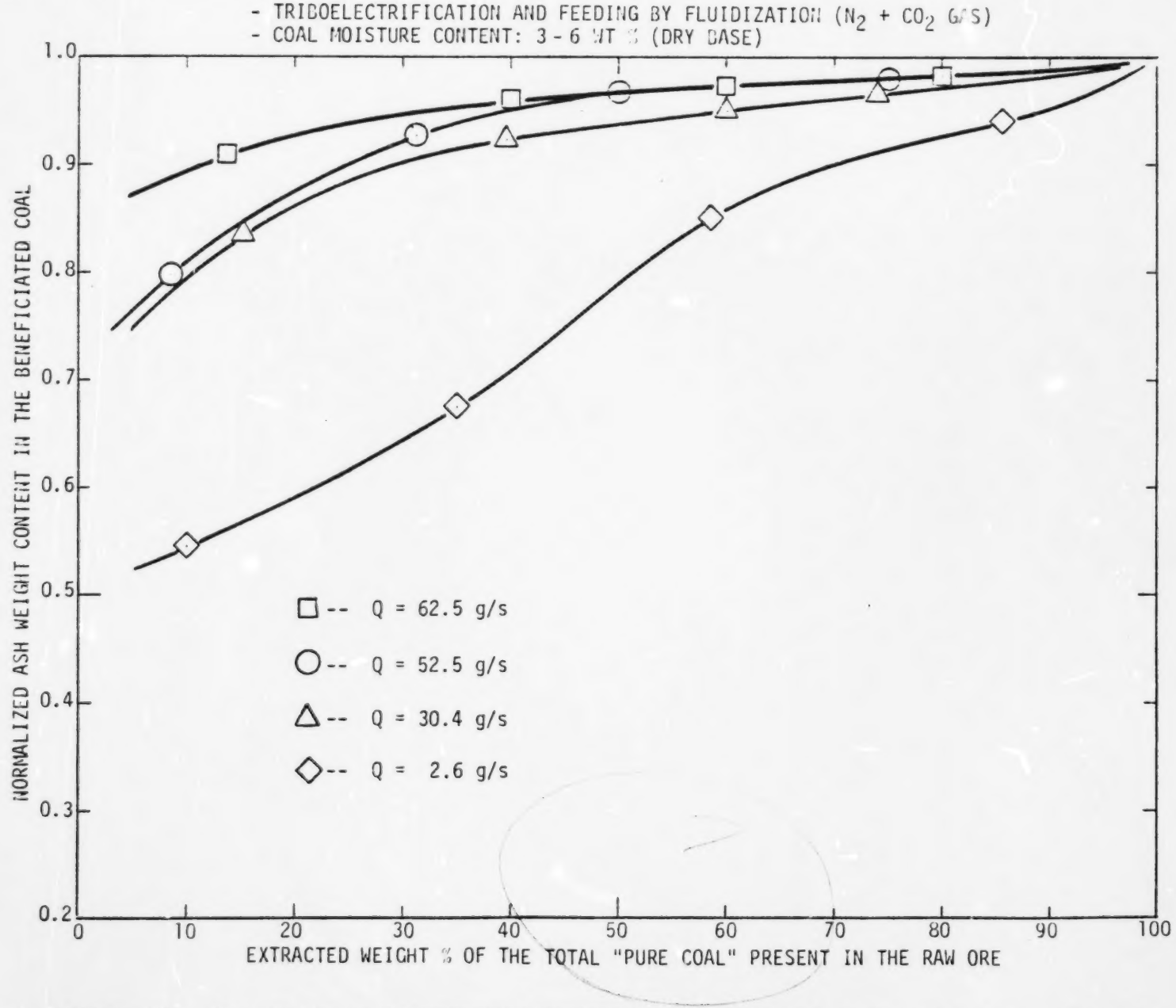


FIGURE 21. ONE-STAGE ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (D_p < 300 μm) AT LOW ELECTRIC FIELDS (E = 0.82 kV/cm) AND VARIOUS RATES OF FEED

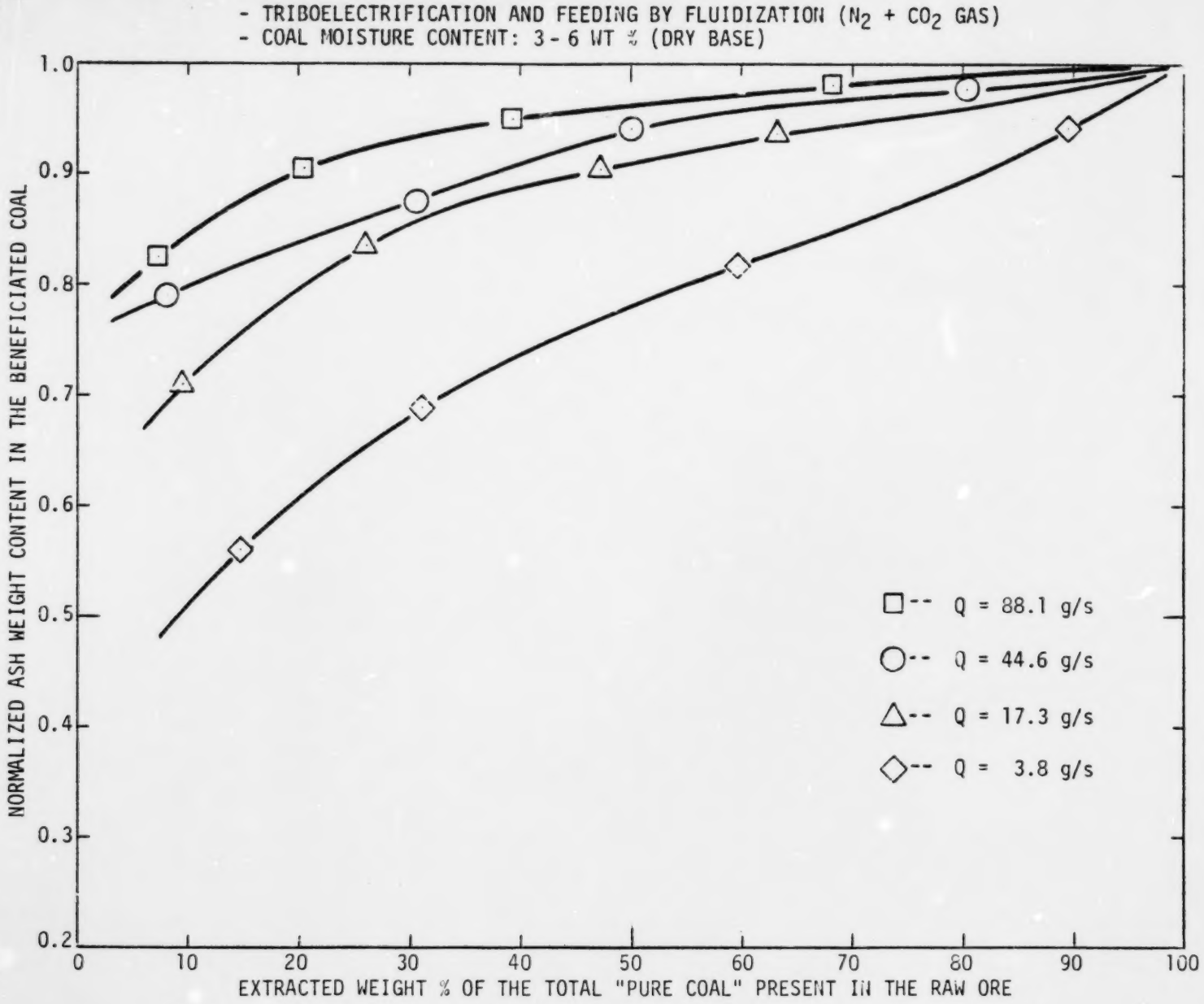


FIGURE 22. ONE-STAGE ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (D_p < 150 μm) AT LOW ELECTRIC FIELDS (E = 0.82 kV/cm) AND VARIOUS RATES OF FEED

The experiments carried out at low electric field intensities are not indicative of the maximum beneficiation which could be obtained at higher field intensities.] The feed rates were varied up to 88 g/s.

An examination of the three sets of beneficiation curves indicates, as expected, that:

1) the < 150 μm particles give, in general, the best results
2) the lower the feed rate, the better the separation.

At the lowest feed rates shown in Figs. 21 and 22 (≈ 3 g/s), it is interesting to note that there is no significant improvement for the < 150 μm particles of the < 300 μm particles. This may be attributed to an entrainment of a greater number of the smaller particles by the gas turbulence in the tower.

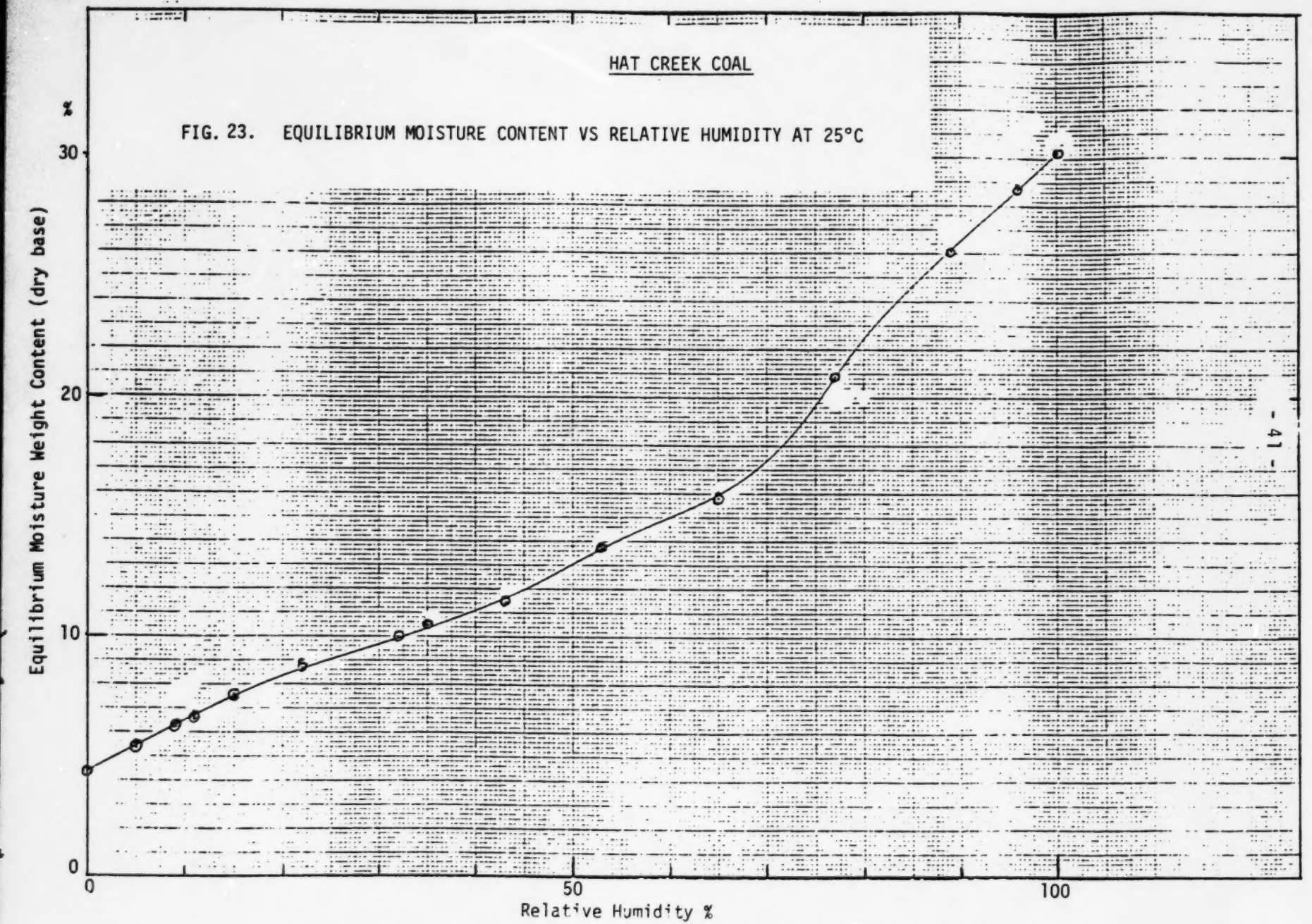
Following the above, it was decided to continue all subsequent tests with coal particles ground to < 150 μm.

ii) Effects of Moisture Content in Coal

It is well known (Ref. 5) that the moisture content, particularly at the surface of the materials, plays a very important role in the triboelectrification process.

Before establishing the levels at which the moisture will have to be controlled, tests were carried out to determine the equilibrium moisture weight content (dry base) as a function of the relative humidity of the ambient. The results are shown in Fig. 23.

As seen from the graph, at relative humidities higher than 70% the equilibrium moisture weight content increases in larger steps for


HAT CREEK COAL
FIG. 23. EQUILIBRIUM MOISTURE CONTENT VS RELATIVE HUMIDITY AT 25°C
%
30
20
10
0
Equilibrium Moisture Weight Content (dry base)
0
50
100
Relative Humidity %

equal steps of relative humidity increase.

Following this, a series of tests was carried out to determine the electrostatic beneficiation that can be achieved with Hat Creek coal batches with moisture contents up to 12% (dry base weight).

The results are shown in Fig. 24. For example, under the particular conditions of the tests for moisture contents below 3.5%, the normalized ash content in the beneficiated coal for a 50% (ash-free coal) recovery will be in the order of 65%. Raising the moisture content to above 5.5%, the normalized ash content in the beneficiated coal will jump to over 95%.

Of particular interest is the very narrow moisture content range from 3.5 to 5.5% (dry base). It can be seen that below 3.5% moisture content one can expect a very stable electrostatic beneficiation process and optimum recoveries. Above 5.5% moisture content, altered tribo-electrification properties and decreased electric charge relaxation time constants are very likely responsible for the poorer performance.

It is believed that these findings could be correlated with the clay hydration as presented in Fig. 7 (p.16).

iii) Effects of the Humidity in the Fluidizing Gas

It was established at A (ii) and E (ii) above that the test coals contained a substantial amount of clay and that for good tribo-electrification the moisture content in coal must be less than 3.5% by weight (dry base). It is also known that clays absorb water at various rates depending on the type of clay and the relative humidity of the ambient.

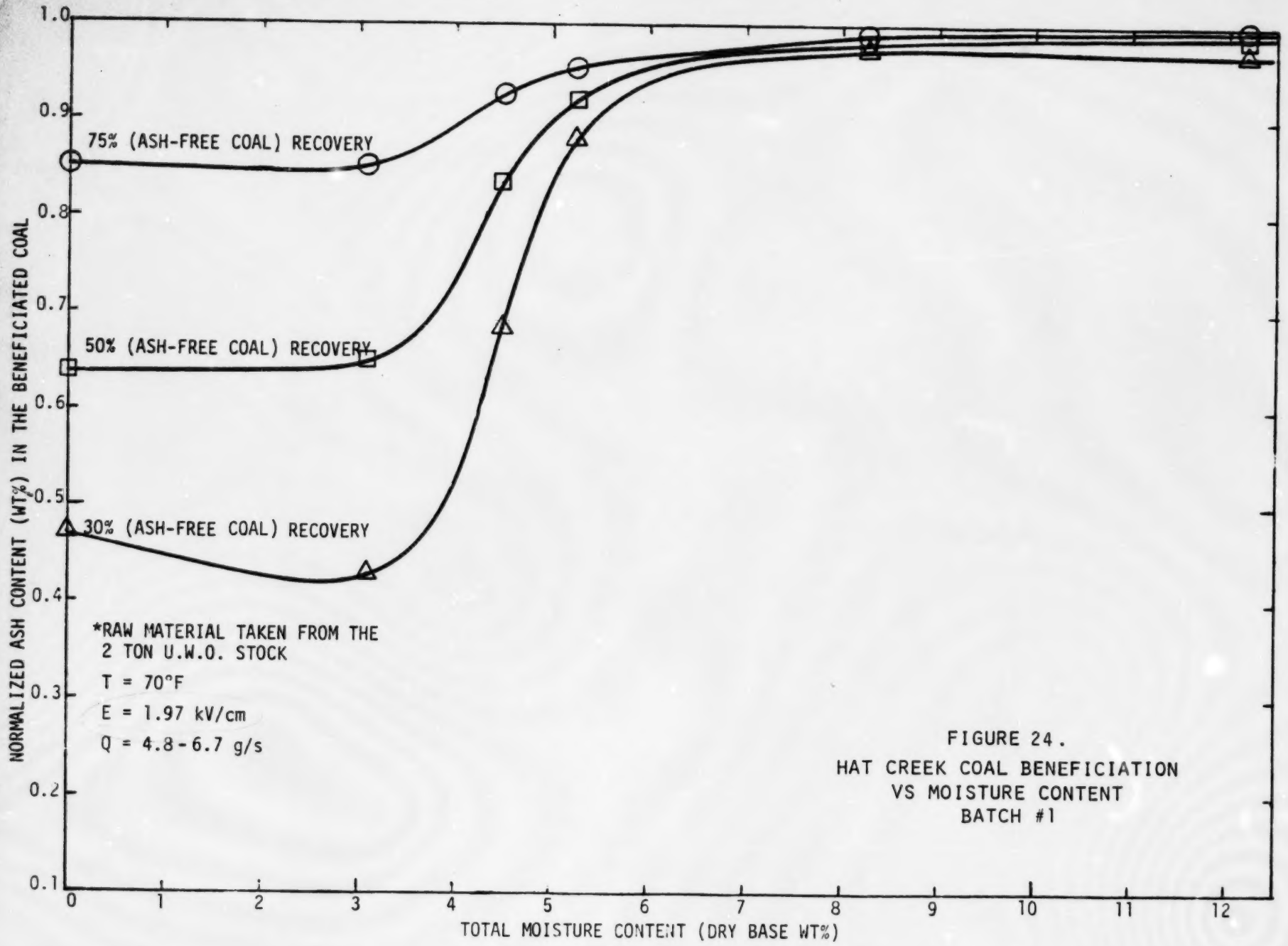


FIGURE 24.
HAT CREEK COAL BENEFICIATION
VS MOISTURE CONTENT
BATCH #1

To determine the influence of the relative humidity of the fluidizing gas on the coal recovery at the 30% ash level, a series of beneficiation tests was carried out on coal Batch #1. The coal was fluidized with synthetic flue gas at various degrees of relative humidity up to 35% RH.

All tests were performed under the conditions outlined on Fig. 25 with particular emphasis on maintaining the adopted 5-minute fluidization and 1.5-minute feeding times constant throughout.

After the calculation of the obtained recoveries, the "ash-free" coal recovery at the 30% ash level was normalized for the dry gas.

It is interesting to note that the recovery characteristic for this coal has a sharp drop at 19% RH.

Considering the variety of clay contents found in the Hat Creek coal and the above findings, before a decision is taken regarding the RH of the fluidizing gas and residence times, it is believed necessary that the entire spectrum of coal be tested in a pilot plant.

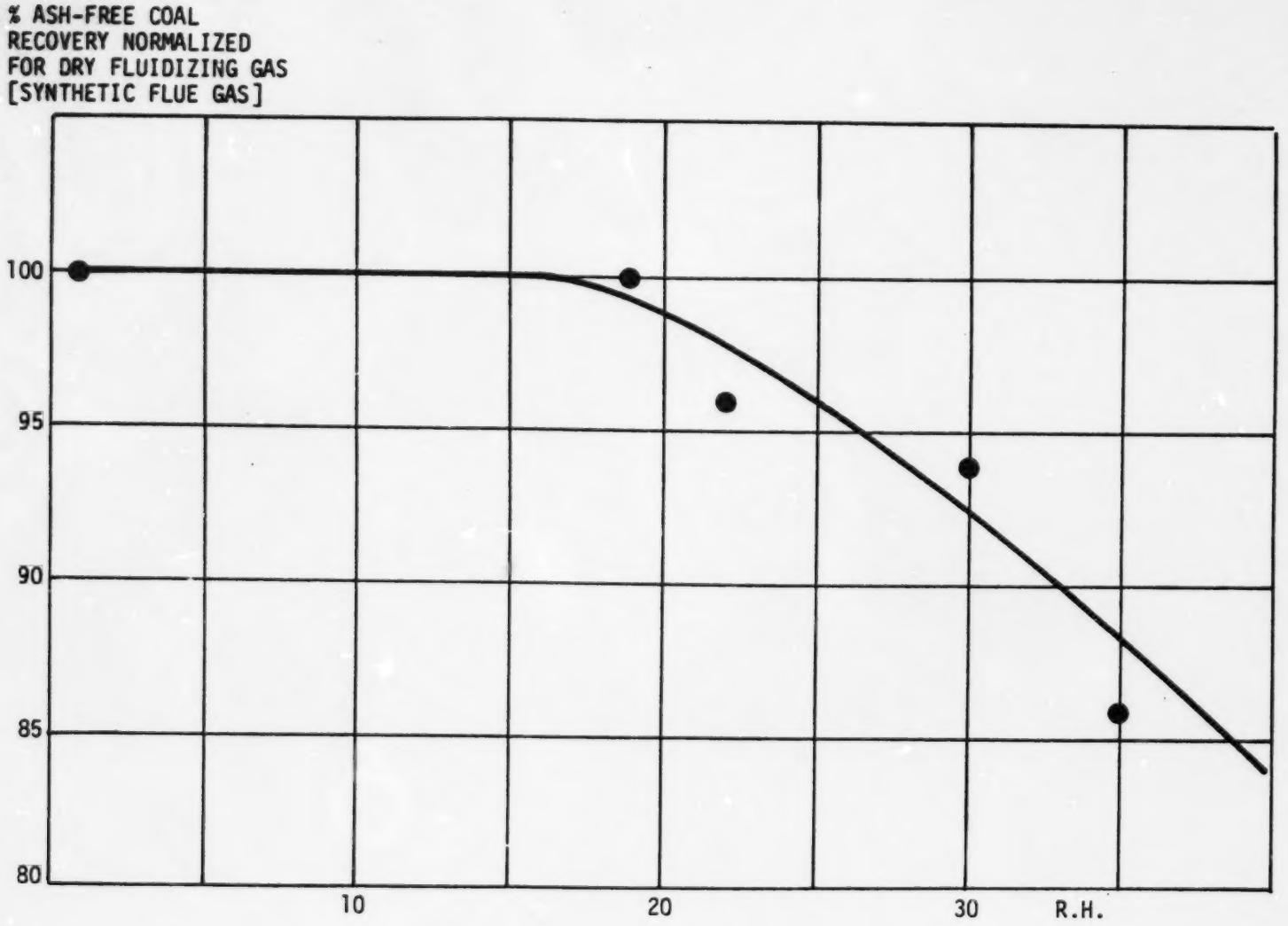


FIG. 25. EFFECTS OF THE RELATIVE HUMIDITY OF THE FLUIDIZING GAS

TEST COAL BATCH #1: Q = 1.7 g/s; E = 1.9 kV/cm
5 MINUTE FLUIDIZATION; 1.5 MINUTE FEED TIME

iv) Effects of the Electric Field Intensity Used in Separation

Fig. 26 shows the effects of the electric field intensity on the collected mass distribution for a more or less constant feed rate. As the electric field intensity used for the separation of the various fractions increases, the mass collected in the central electrodes diminishes for a corresponding increase in the side trays 1 and 2, and 11 and 12.

Fig. 27 shows the mass distribution of the coal collected in the twelve trays of the experimental tower for various rates of feed at a constant electric field intensity of relatively low value (E = 0.82 kV/cm). One can see that at high feed rates the mass collected in some of the central trays (5, 6 and 7) is three to four times greater than the mass collected in the trays near the separation electrodes.

Fig. 28 shows the beneficiation results for two values of the electric field intensity.

From the above results, it is obvious that the higher field intensities offer the double advantage of an increased recovery and a sharper definition of the ash-rich and coal-rich fractions.

v) Beneficiation for Various Mineral Matter Contents in the Raw Coal

Some of the graphs presented in this section have been prepared in order to put the experimental findings into better perspective and, at the same time, to facilitate comparisons with other methods. All data have been prepared on the assumption that the beneficiated coal to be burned in the future power plant will have an ash content of 30%

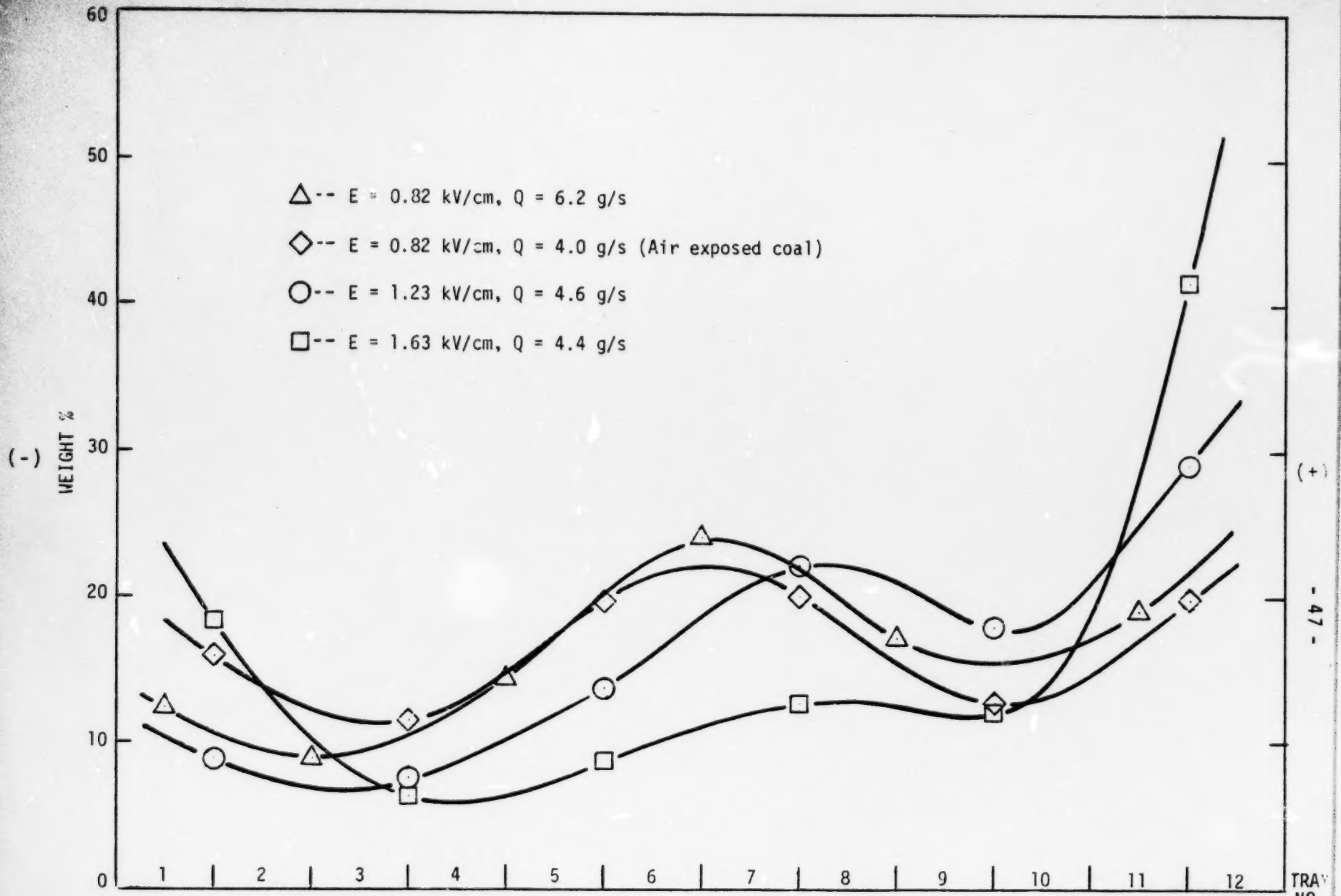


FIGURE 26. DISTRIBUTION OF < 150 μm COAL COLLECTED IN TRAYS FOR VARIOUS ELECTRIC FIELD INTENSITIES

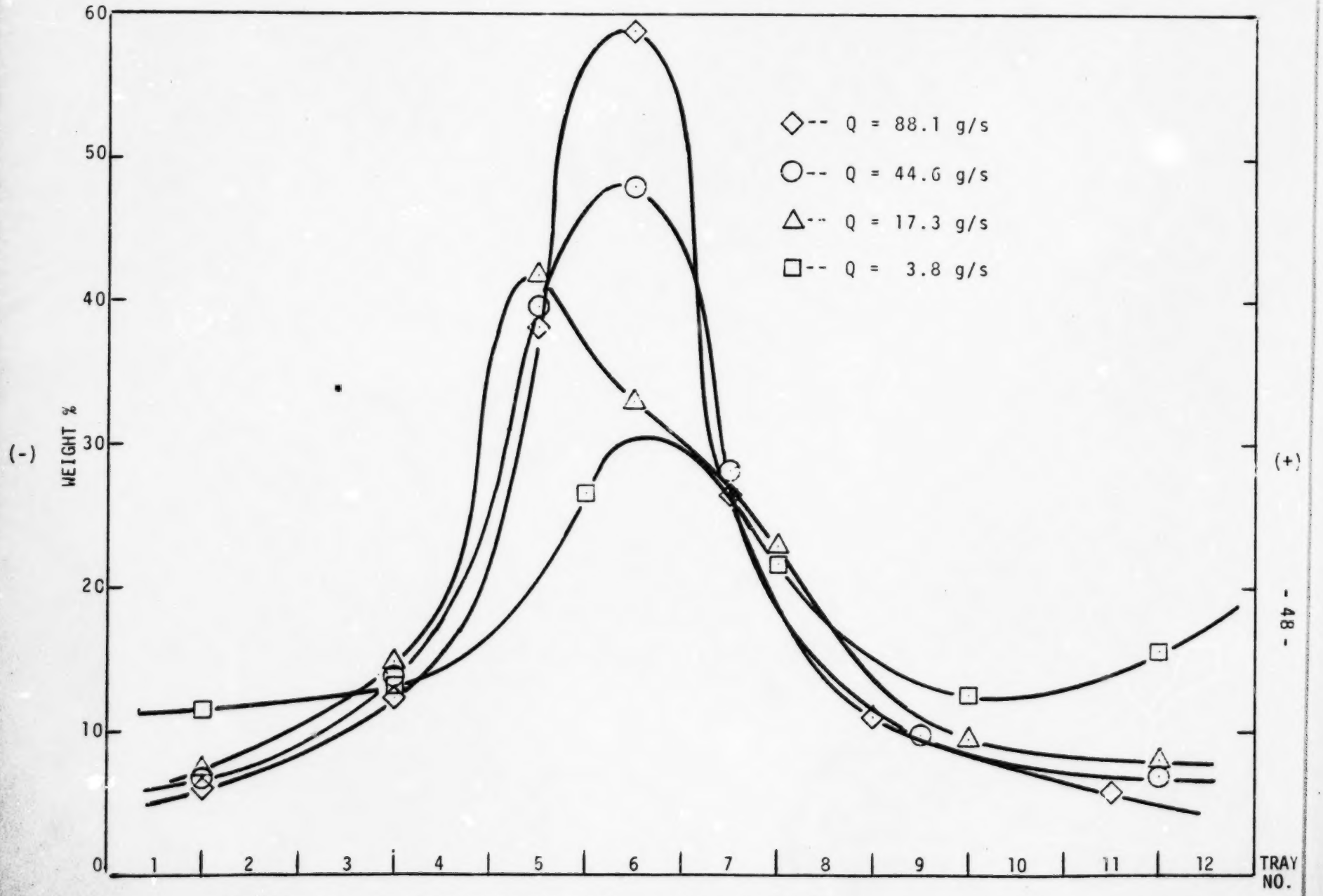


FIGURE 27. DISTRIBUTION OF < 150 μm COAL COLLECTED IN TRAYS FOR VARIOUS RATES OF FEED AT CONSTANT ELECTRIC FIELD (E = 0.82 kV/cm)

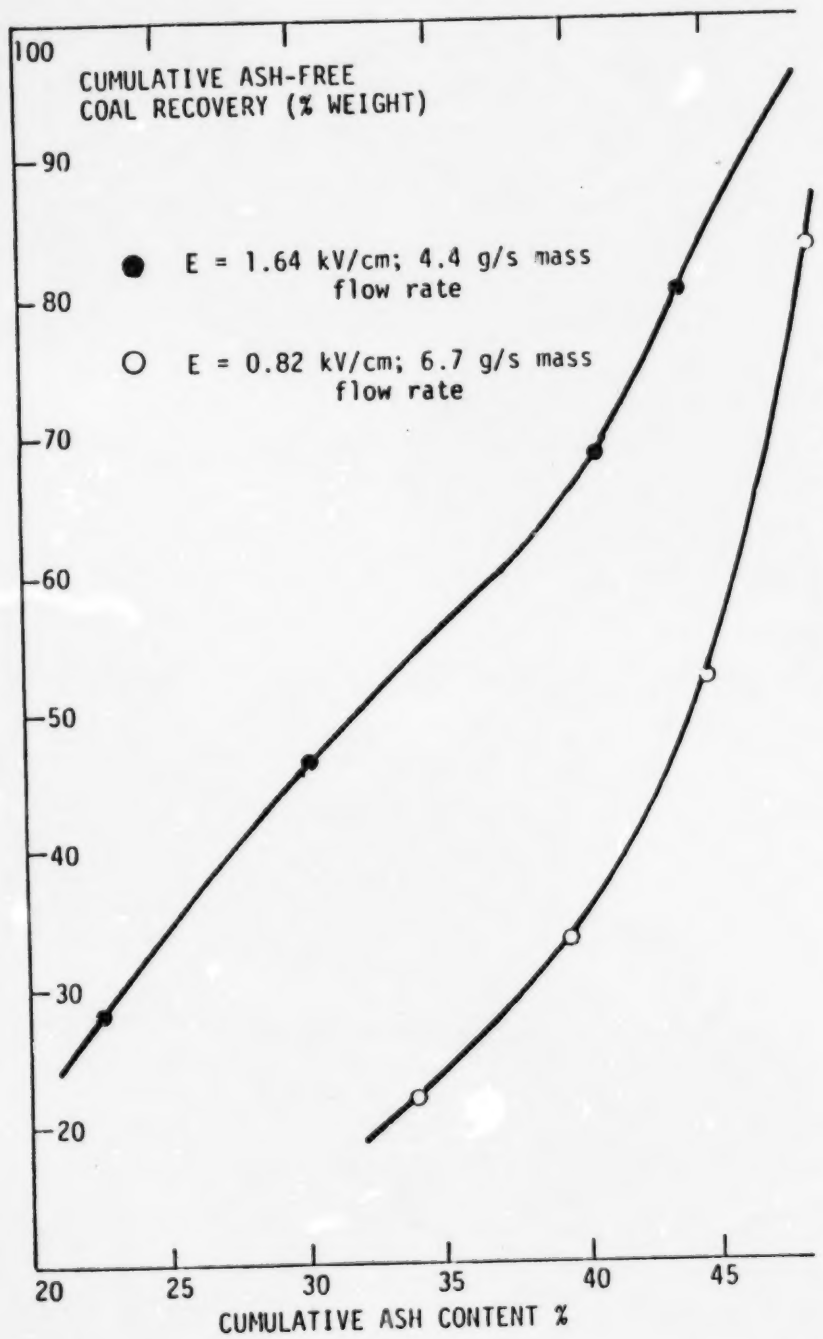


FIGURE 28. ELECTROSTATIC BENEFICIATION OF HAT CREEK COALS (D_p < 150 μm) IN SYNTHETIC FLUE GAS (COAL MOISTURE CONTENT: 3 - 6%)

(dry base weight) which is equivalent to 25% ash at 20% moisture.

To make it easier to assess and compare the electrostatic beneficiation results with beneficiation by washing, the Btu recoveries have been calculated using the same Dolmage Campbell formula for Btu calculations (Btu = 13003 - 151.98 Ash).

Fig. 29 shows the necessary minimum ash content in the reject in order to achieve the various ash-free coal recoveries. The curves are based on the formula

$$P_{ash} = \frac{y - 0.429\ p_c\ (1 - y/100)}{100 - 1.429\ p_c\ (1 - y/100)} \times 100$$

P_{ash} = minimum necessary % ash content in the rejected material to produce a (30% ash) coal at p_c% (ash-free) recovery starting with a y% ash raw material.

For example, let us consider a target recovery of 90% ash-free coal from the raw material with which the current experiments are being carried out. The raw material contains approximately 50% ash. The respective curve in Fig. 29 shows that in order to reach this target the reject must contain a minimum of 86% ash. To our knowledge none of the experiments produced coal fractions having an 86% ash content.

Similarly, if one were to use a raw material with 40% ash, a reject with a minimum ash content of 73% will suffice to reach the 90% recovery target.

If one considers the Btu in lieu of the ash-free coal recovery, such recoveries are dependent upon the ash content in the raw material.

Fig. 30 shows the Btu recovery and the necessary minimum ash content in the reject when starting with a raw material containing 40%

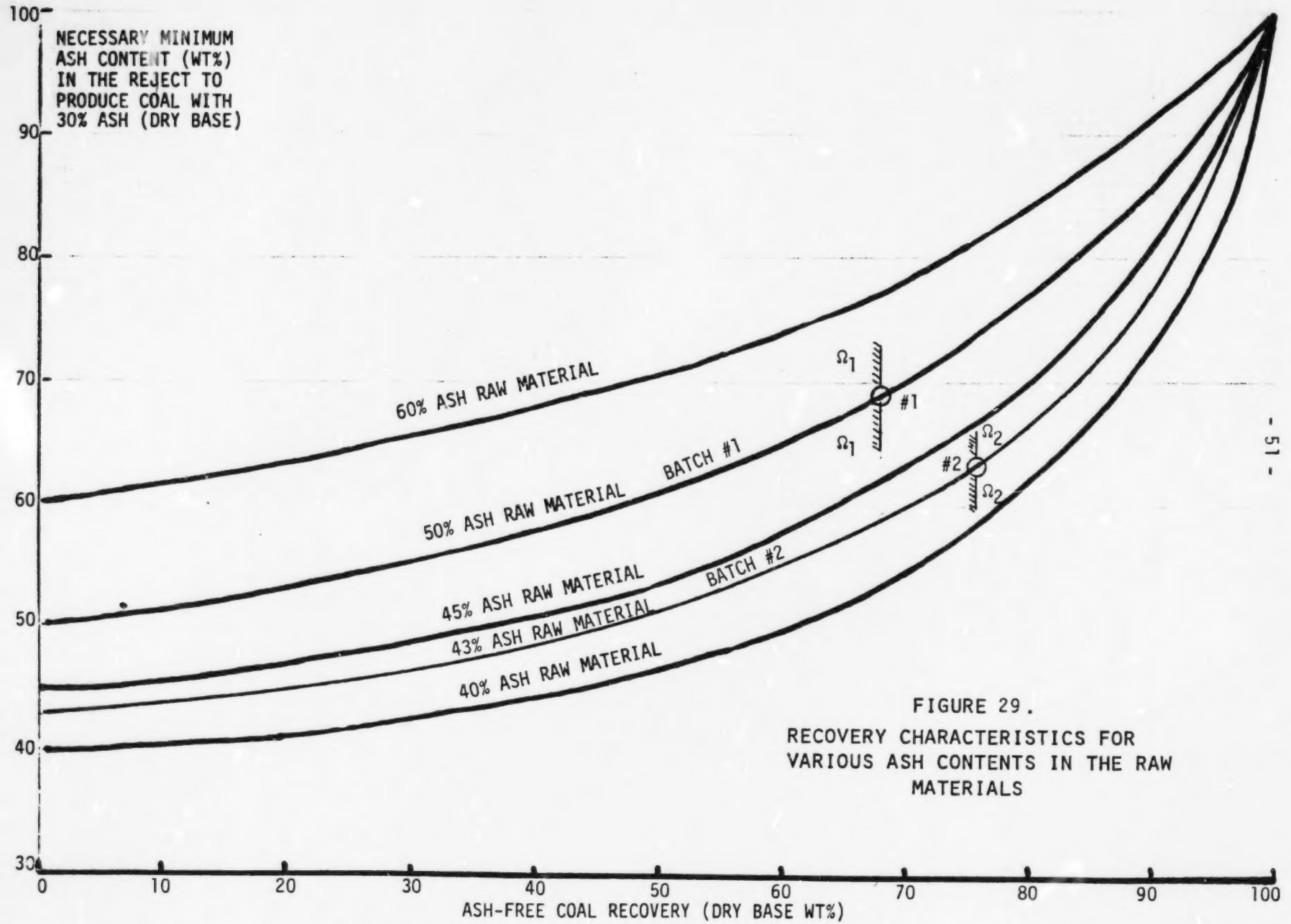


FIGURE 29.
RECOVERY CHARACTERISTICS FOR VARIOUS ASH CONTENTS IN THE RAW MATERIALS

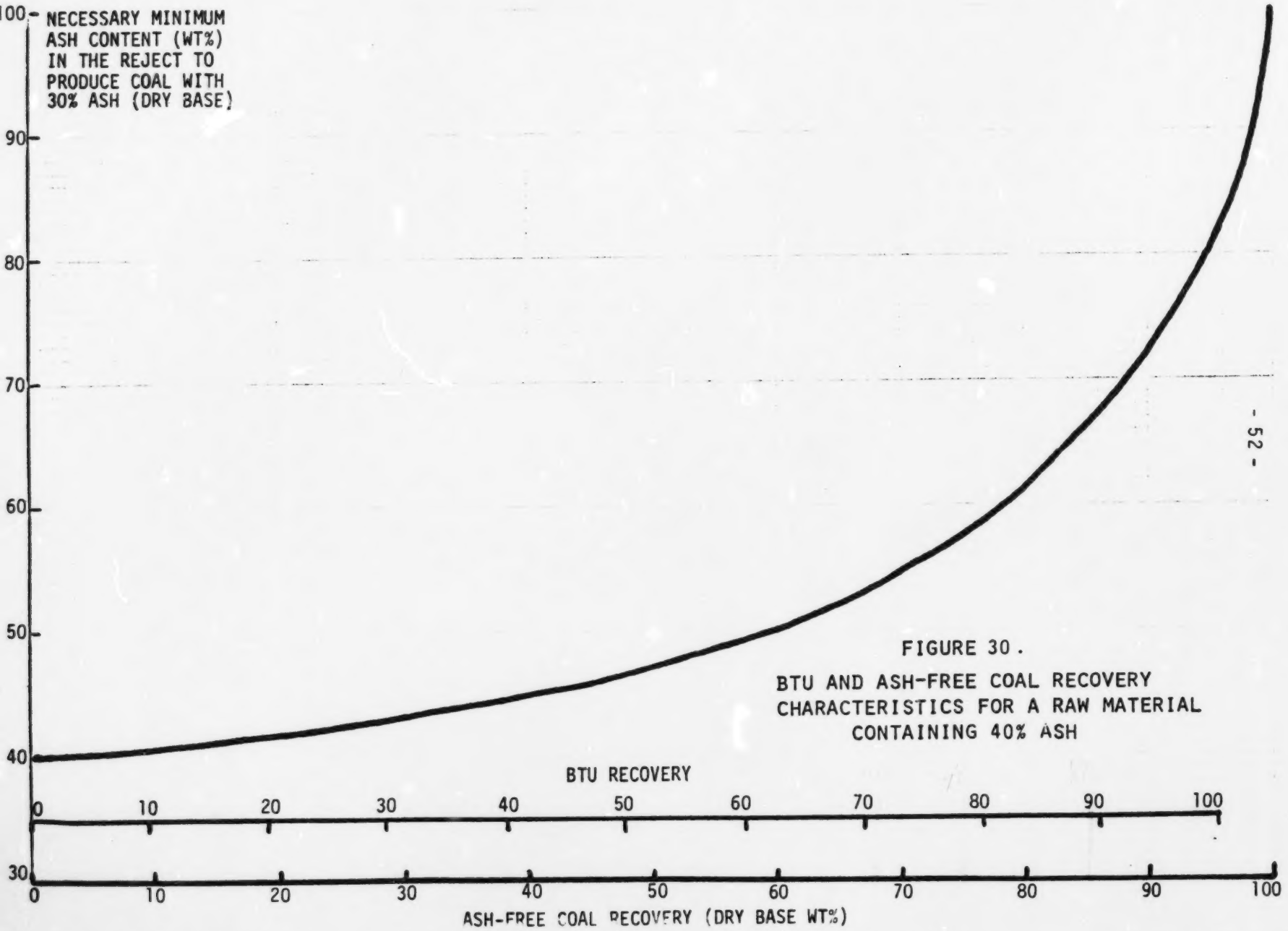


FIGURE 30.

BTU AND ASH-FREE COAL RECOVERY CHARACTERISTICS FOR A RAW MATERIAL CONTAINING 40% ASH

ash. In such case, if one were to assume a target Btu recovery of 80%, one would require to reject coal with a minimum ash content of 59%.

Fig. 31 shows that for a raw material containing 50% ash, such as the one investigated by The University of Western Ontario, an 80% Btu recovery will require to separate and reject coal which has an ash content of a minimum of 71%.

On Figs. 29 and 31, marked with the letters Ω_1-Ω_1 and Ω_2-Ω_2, are some beneficiation levels obtained during experiments with Batch #1 and Batch #2, respectively. The intersection points #1 and #2 show the necessary minimum ash contents in the rejects.

vi) Multistage Beneficiation

a) Multistage Beneficiation at Reduced Electric Fields (Batch #1)

Table II shows the results of low voltage, multistage beneficiation experiments with coal particles in the < 150 μm range, fluidized by means of synthetic flue gas. This series of experiments was carried out in order to determine the behaviour of reprocessed coal with various ash concentrations.

Under the conditions of this multistage test, Stage IV appears to be the last worthwhile beneficiation. At Stage V the best fraction that one can obtain contains 51.6% ash. In one of the special trials, shown by the various arrows in Table II, the material collected in trays 2, 3, 4, 5 and 6 of Stage IV was mixed with the material collected in trays 1 and 2 of Stage V, and reprocessed as Stage VI under a higher electric field intensity (E = 1.23 kV/cm).

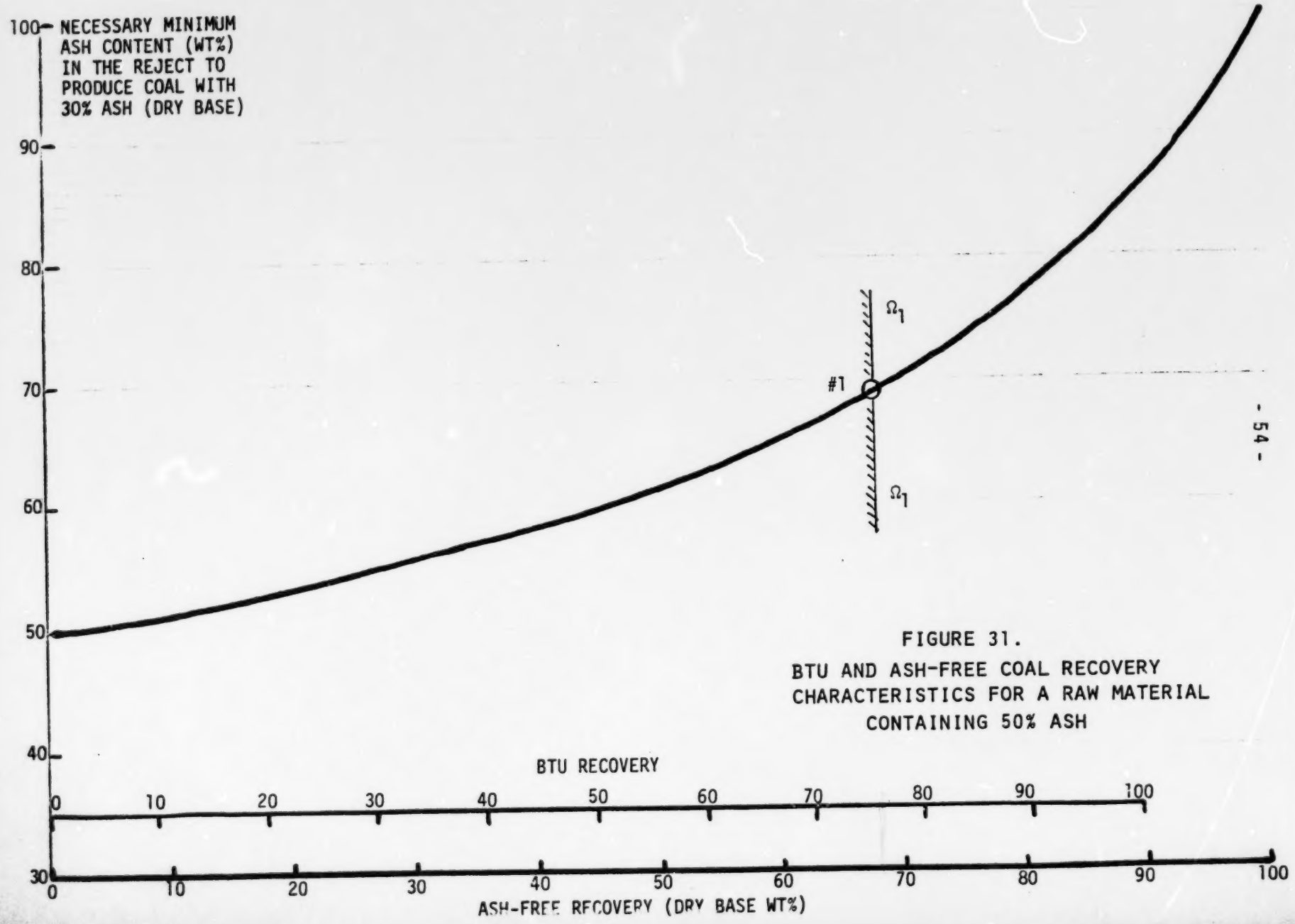
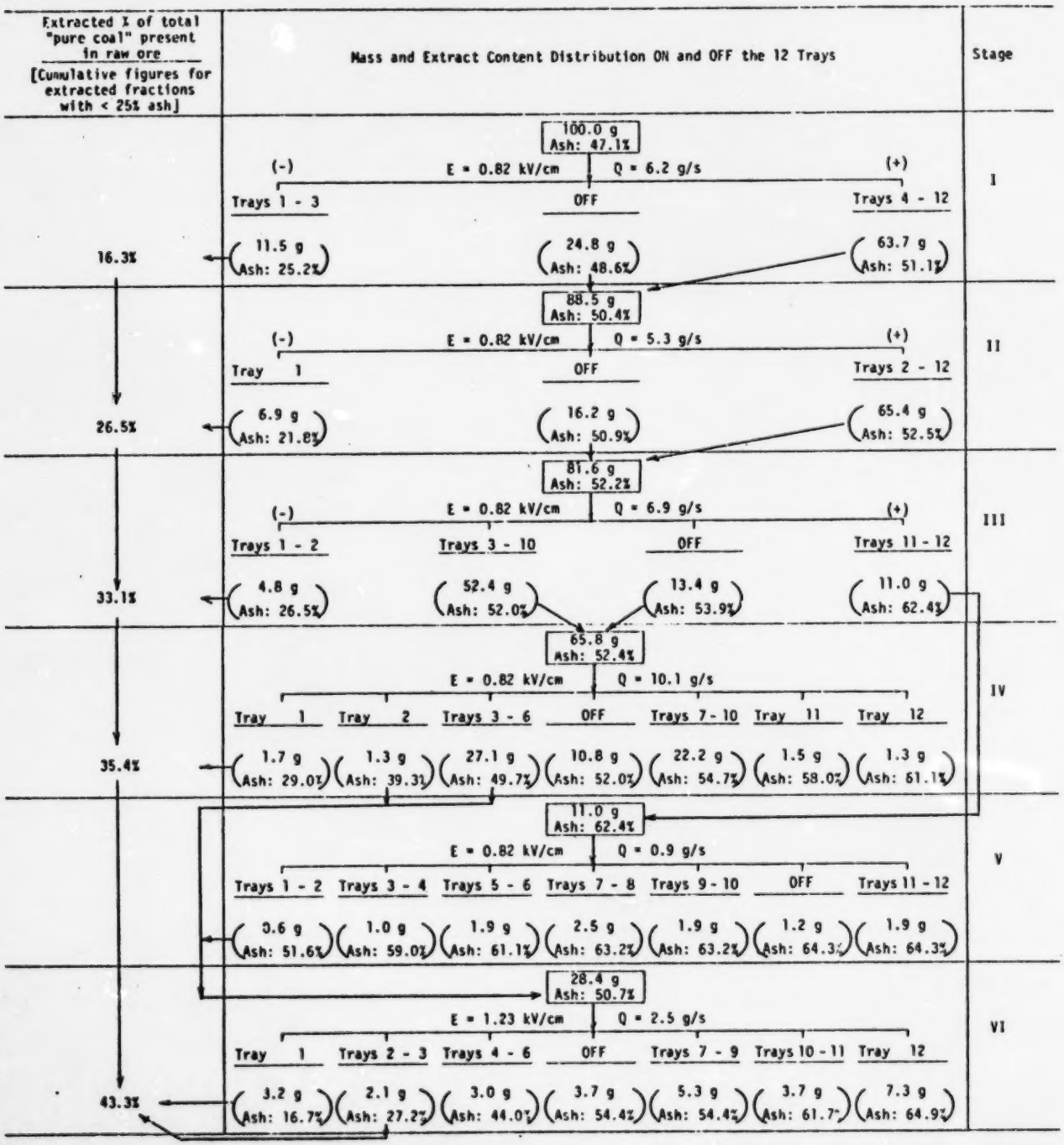


FIGURE 31.
BTU AND ASH-FREE COAL RECOVERY CHARACTERISTICS FOR A RAW MATERIAL CONTAINING 50% ASH

TABLE II. LOW VOLTAGE, MULTISTAGE EXPERIMENTS FOR THE ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL



Coal Particles < 150 μm with 3 - 5% moisture content (dry base)
Q - feed flow rate (g/sec)
Ash % - calculated for the dry base mass
E - electric field intensity (kV/cm)

The 28.4 g of material containing 50.7% ash, which appeared to be unsuitable for further separation, yielded in trays 1, 2 and 3, 18% more coal with less than 25% ash content (3.2 g + 2.1 g).

Fig. 32 shows, for comparison purposes, the results obtained from the various beneficiation tests specified on the graph.

It is interesting to note that:

a) The freshly ground coal shows an improvement over the oxidized coal. This confirms some similar tests carried out at an earlier date with Eastern Canada coals.

b) The beneficiation carried out after triboelectrifying the coal by means of vibration is comparable to that obtained when the coal is triboelectrified by means of fluidization.

c) The one-stage beneficiation carried out with new coal after triboelectrification by means of vibration and in a higher electric field intensity of 1.64 kV/cm gave better results than what could be achieved after five stages of beneficiation which are detailed in Table II.

b) Electrostatic Beneficiation Preceded by Electrostatic Sizing of a Coarse Grind (Batch #1)

Following the report of the Western Research Laboratory that the < 100 mesh fraction has a high ash content, it has been decided to try an electrostatic sizing of a coarsely ground material prior to the electrostatic beneficiation of the < 150 μm fraction.

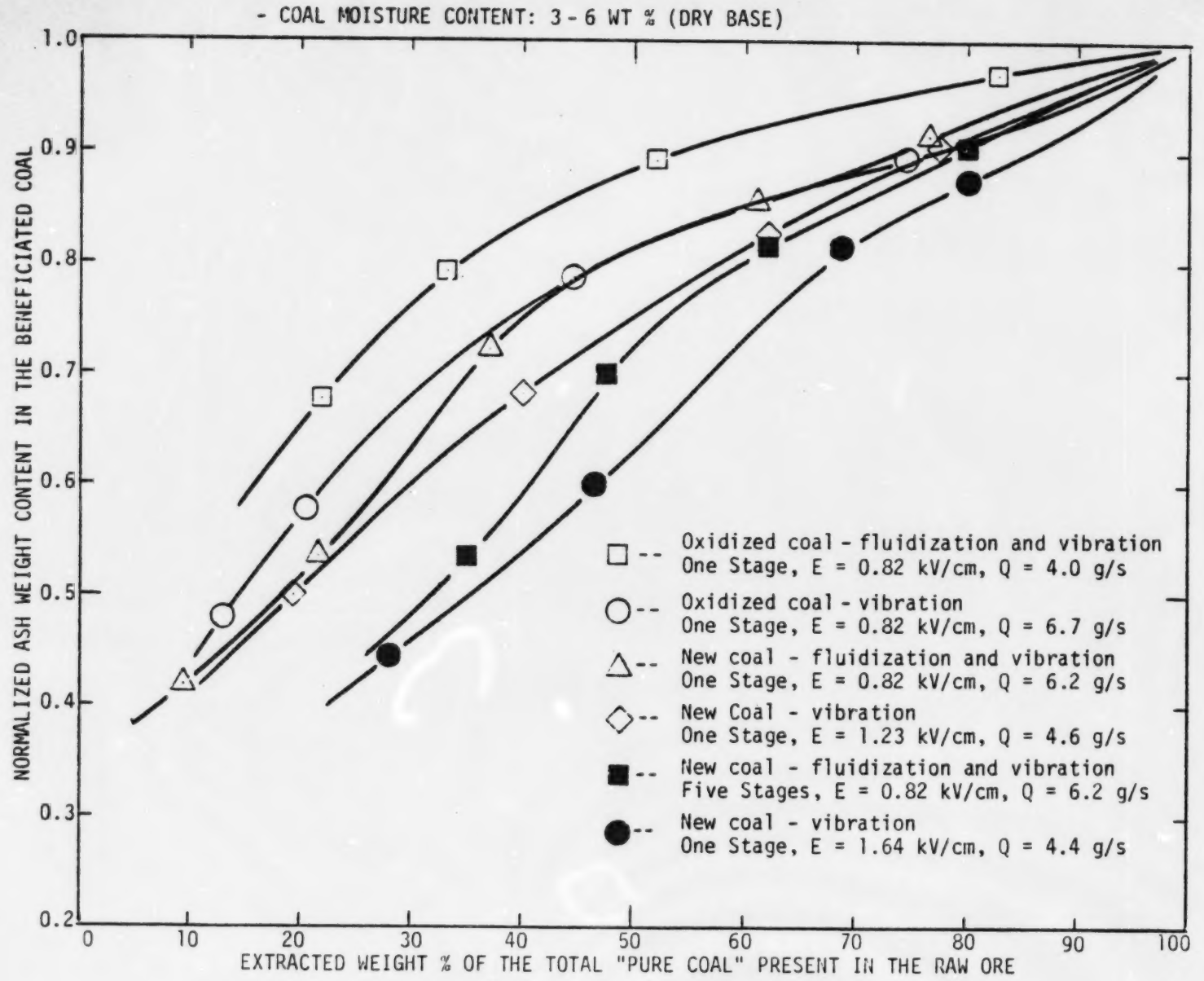

- COAL MOISTURE CONTENT: 3 - 6 WT % (DRY BASE)
NORMALIZED ASH WEIGHT CONTENT IN THE BENEFICIATED COAL
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
10
20
30
40
50
60
70
80
90
100
EXTRACTED WEIGHT % OF THE TOTAL "PURE COAL" PRESENT IN THE RAW ORE
Oxidized coal - fluidization and vibration
One Stage, E = 0.82 kV/cm, Q = 4.0 g/s
Oxidized coal - vibration
One Stage, E = 0.82 kV/cm, Q = 6.7 g/s
New coal - fluidization and vibration
One Stage, E = 0.82 kV/cm, Q = 6.2 g/s
New Coal - vibration
One Stage, E = 1.23 kV/cm, Q = 4.6 g/s
New coal - fluidization and vibration
Five Stages, E = 0.82 kV/cm, Q = 6.2 g/s
New coal - vibration
One Stage, E = 1.64 kV/cm, Q = 4.4 g/s

FIGURE 32. ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (D_p < 150 μm) IN SYNTHETIC FLUE GAS WITH THE VARIOUS PARAMETERS: ELECTRIC FIELDS, STAGES OF PROCESSING, RATE OF FEED, TYPE OF TRIBOELECTRIFICATION, AS SHOWN

The Hat Creek coal as received from B.C. Hydro was ground to < 5 mm, was dried and allowed to free fall in the electrostatic tower in an electric field of 1.97 kV/cm. As the coarser particles are more difficult to fluidize with our laboratory equipment, a Syntron feeder was used to feed the material.

At the bottom of the tower three fractions were collected as shown in Schematic Block Diagram #1.

The X fraction of fines collected at the (-) electrode had 22.0% ash (dry base), those collected at the (+) electrode had 63.1% ash (dry base), and the main mass of heavier particles collected in the centre had approximately the same ash content as the original material.

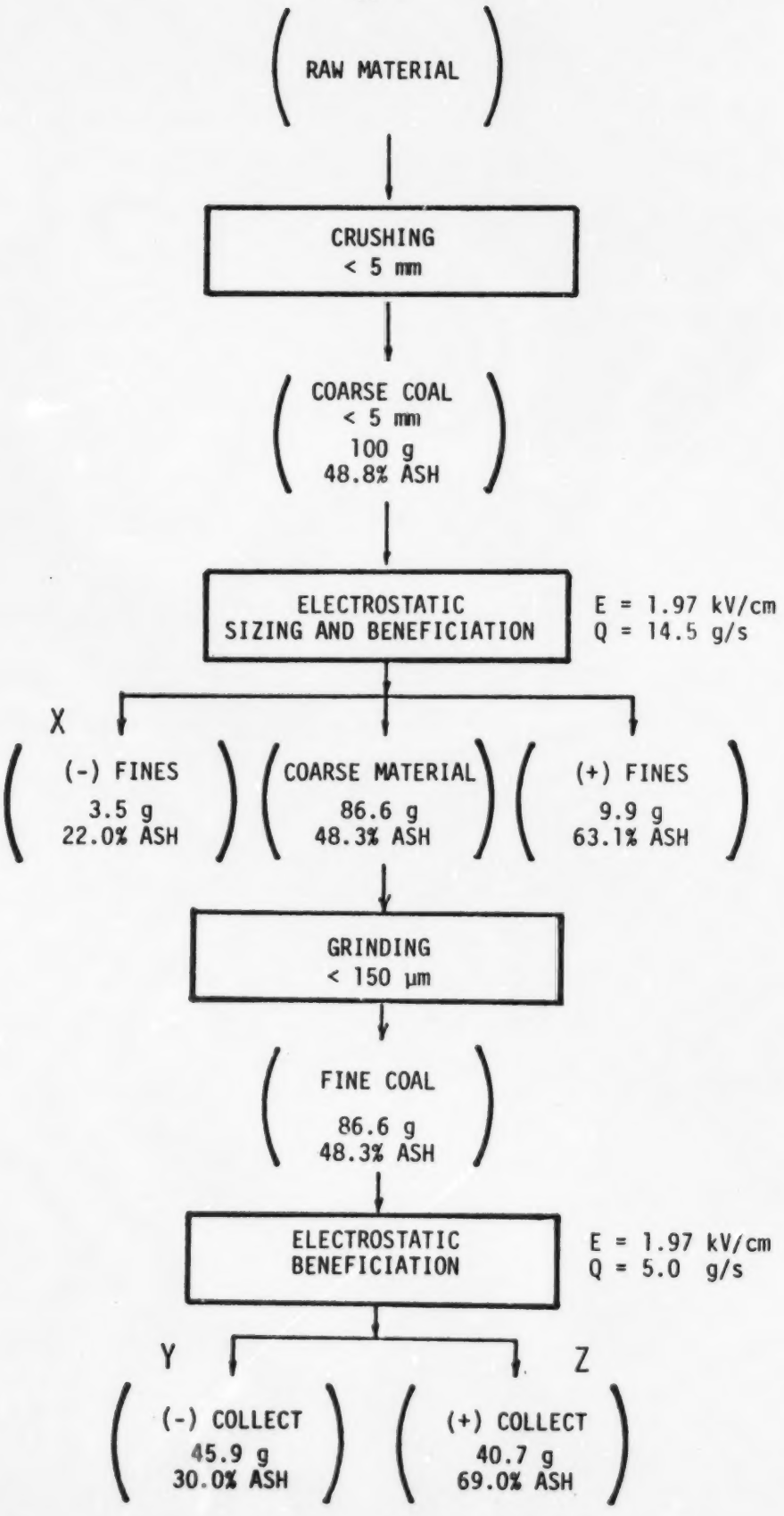
The main fraction (86.6 g) collected in the centre, and which was composed mostly of coarse particles, was ground to < 150 μm and reprocessed in the tower.

Two fractions were obtained: the Y fraction at the (-) electrode containing 45.9 g with 30% ash and the Z fraction at the (+) electrode containing 40.7 g with 69% ash.

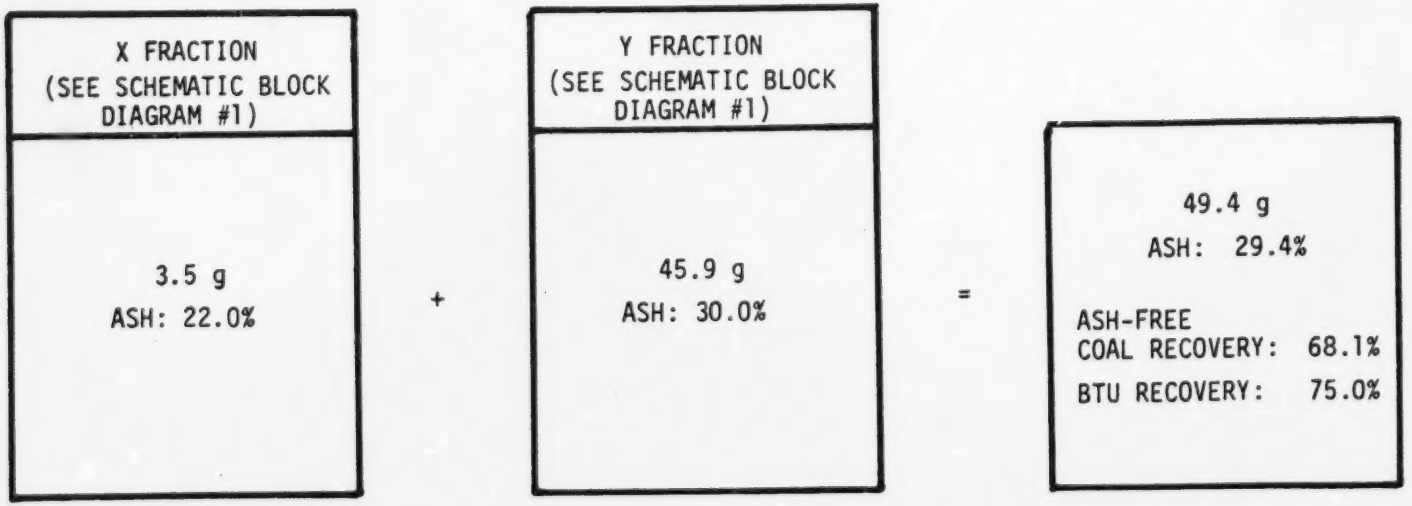
Schematic Block Diagram #2 shows the ash-free coal and Btu recoveries.

Subsequent to this, the 40.7 g Z fraction was reprocessed alone with the results shown in Schematic Block Diagram #3. It is interesting to note that the mass collected in the positive section of the tower (4.7 + 8.5 + 9.1 = 22.3 g; equivalent to ≈ 55% of the total mass) contained in excess of 75% ash.

Referring to Fig. 31, 75% ash content is the necessary minimum for an 86% Btu recovery.

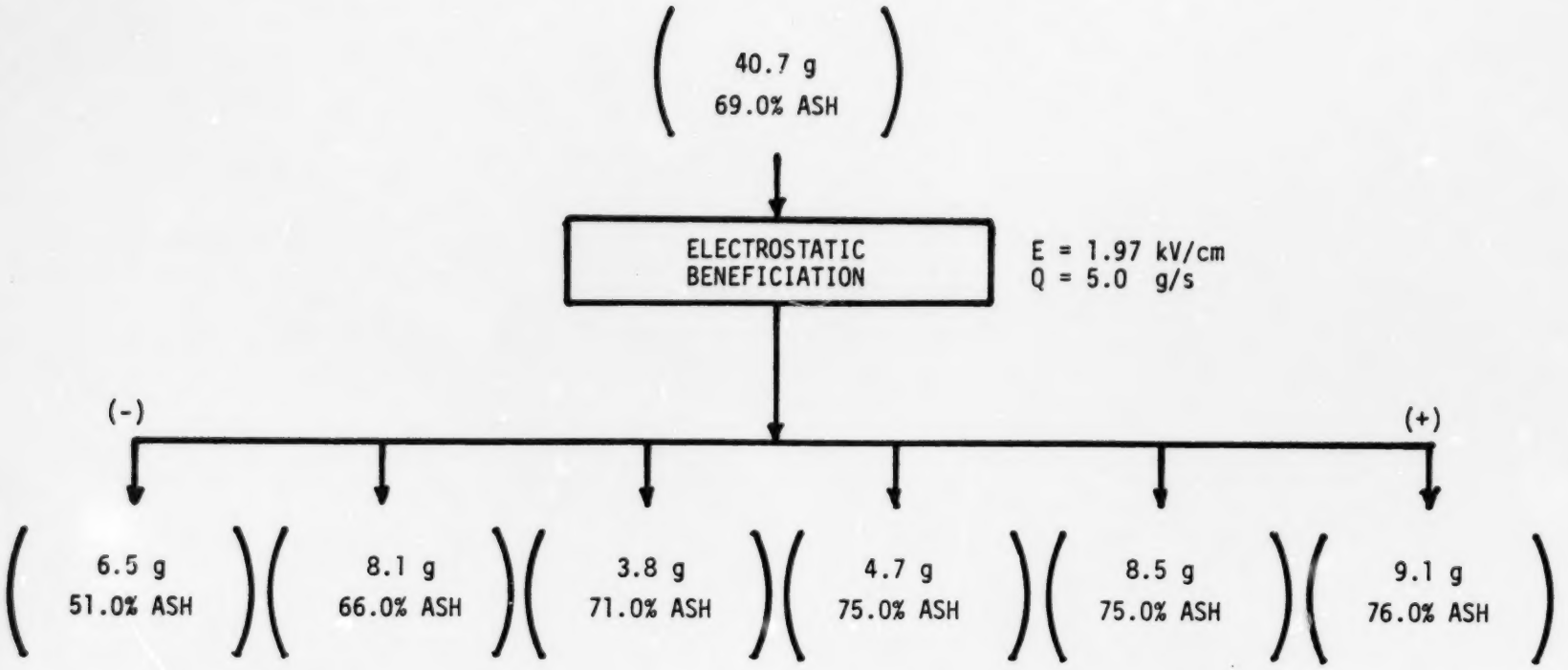


SCHEMATIC BLOCK DIAGRAM #1. QUANTITIES REDUCED TO 100 g



SCHEMATIC BLOCK DIAGRAM #2.

ASH-FREE COAL AND BTU RECOVERY IN THE PROCESS OUTLINED IN SCHEMATIC BLOCK DIAGRAM #1



SCHEMATIC BLOCK DIAGRAM #3. BENEFICIATION OF Z FRACTION

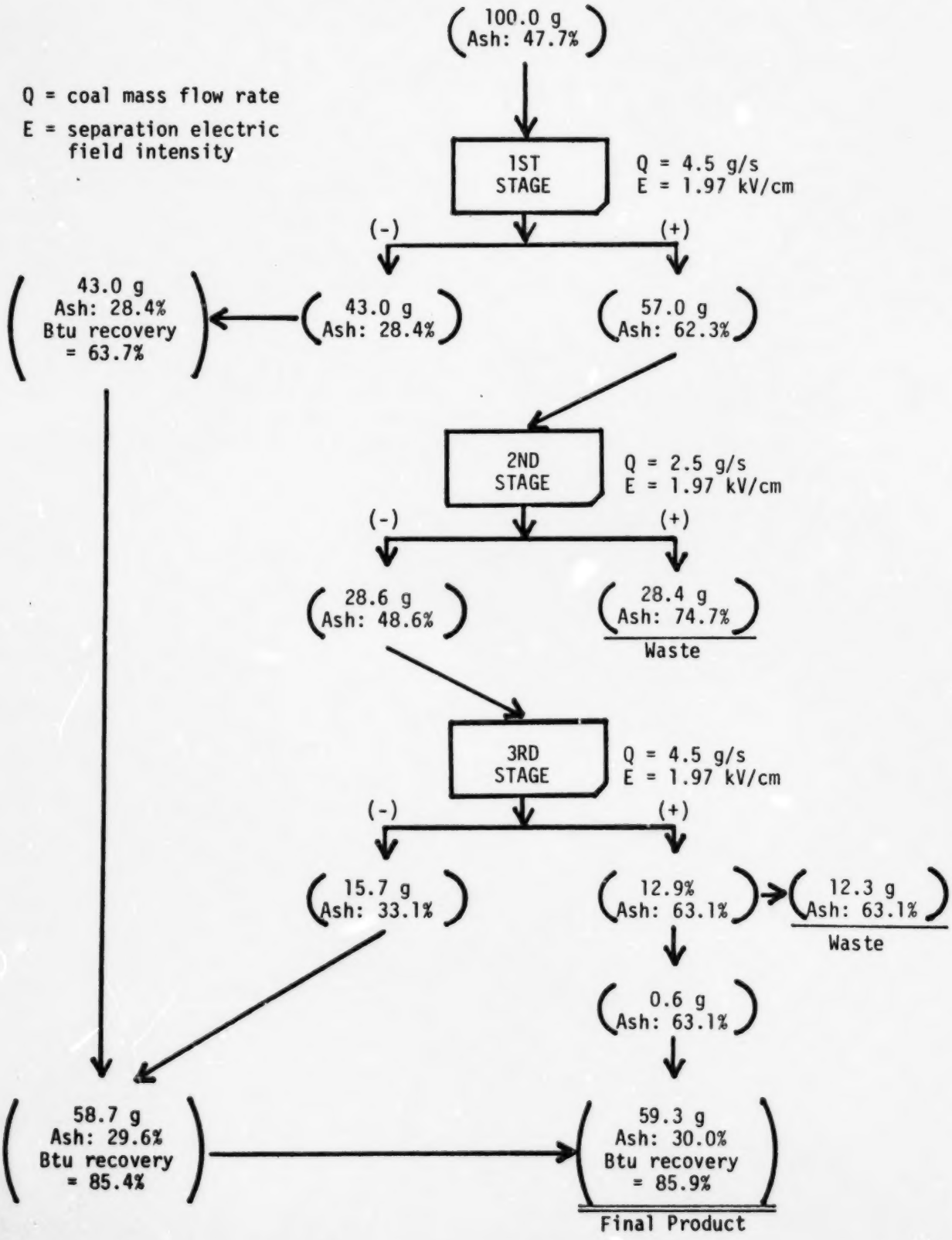
(SEE SCHEMATIC BLOCK DIAGRAM #1)

c) 3-Stage Beneficiation at High Electric Fields (Batch #1)

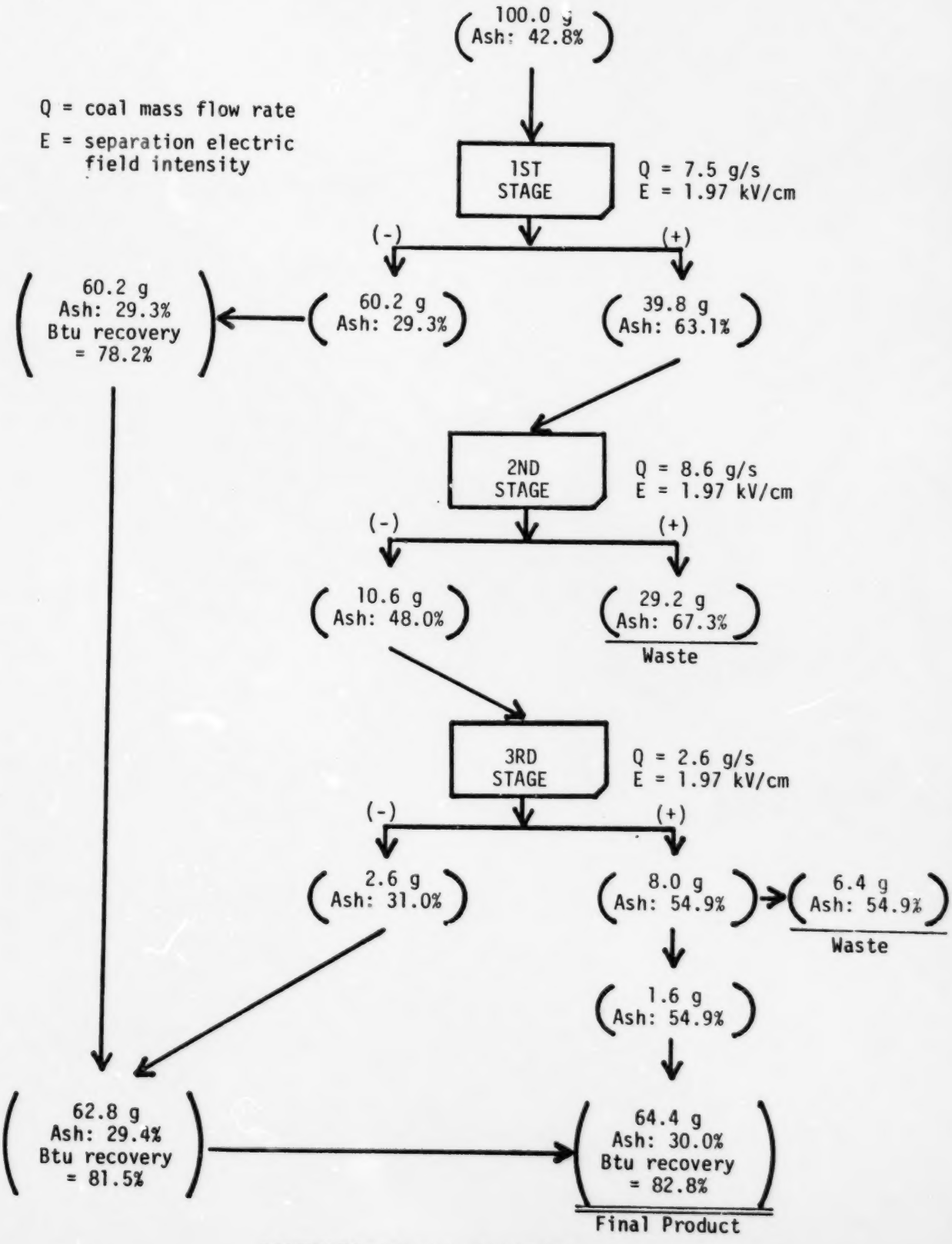
In order to investigate what may be the maximum obtainable recoveries, through electrostatic beneficiation of the 48% ash coal, a 3-stage beneficiation was carried out under most favourable conditions of low mass flow (4.5 g/s) and high electric field (1.97 kV/cm). The results are shown in Schematic Block Diagram #4 where a Btu recovery of 85.9% at 30% ash was obtained.

d) 3-Stage Beneficiation at High Electric Fields (Batch #2)

The 43% ash coal was also beneficiated in a 3-stage process as shown in Schematic Block Diagram #5. The Btu recovery reached 82.8% at 30% ash.



SCHEMATIC BLOCK DIAGRAM #4
3-STAGE ELECTROSTATIC BENEFICIATION FOR 48% ASH COAL (BATCH #1)



SCHEMATIC BLOCK DIAGRAM #5
3-STAGE ELECTROSTATIC BENEFICIATION FOR 43% ASH COAL (BATCH #2)

vii) Final Tests

a) Coal Batch #1

For the final experiments with coal Batch #1, a series of five single-stage beneficiation tests was performed under the conditions and with the results shown in Table III. The close range of five experimental results indicates that an adequate process control was achieved and that the test coal samples were fairly uniform in composition and triboelectrification properties.

b) Coal Batch #2

Same as for Batch #1, the final experiments with coal Batch #2 consisted of a series of five single-stage beneficiation tests. They were performed under the conditions and with the results shown in Table IV. The closeness of the experimental points reaffirm the adequacy of the process control and uniformity of the samples taken from this batch.

TABLE III. FINAL TESTS - ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (BATCH #1)

Test conditions:

Average electric field intensity, E = 1.97 kV/cm
Average mass flow rate = 14 g/s
Coal moisture content - less than 3.5% dry base
Fluidizing gas - synthetic flue gas

Test #	% ash content in test coal (dry base)	% Btu* (Recovery)
1-1	47.2	75
1-2	48	75.5
1-3	48	79.5
1-4	48.5	77
1-5	49	75.5
Average values	48.14%	76.5%

*Btu calculated with Dolmage Campbell Formula

Coal-rich fractions collected at (-) electrode

TABLE IV. FINAL TESTS - ELECTROSTATIC BENEFICIATION OF HAT CREEK COAL (BATCH #2)

Test conditions:

Average electric field intensity, E = 1.97 kV/cm
Average mass flow rate = 14 g/s
Coal moisture content - less than 3.5% dry base
Fluidizing gas - synthetic flue gas

Test #	% ash content in test coal (dry base)	% Btu* (Recovery)
2-1	42.4	78.2
2-2	42.4	80.5
2-3	42.7	80.5
2-4	43.4	80.5
2-5	43.6	81.0
Average values	42.9%	80.14%

*Btu calculated with Dolmage Campbell Formula

Coal-rich fractions collected at (-) electrode

F. MINERALOGY OF THE ELECTROSTATIC SEPARATES

i) Test Coal Batch #1

The mineralogy of the electrostatic separates was checked by x-ray powder diffraction as shown in Fig. 33 for Batch #1. In the figure, trace (a) was obtained on the bulk sample having a coal:ash ratio of 50:50 (as obtained by calcining at 750°C). The ash residue of the bulk sample after coal removal by H_2O_2 is illustrated by trace (b). The powder pattern for the ash residue of the ash-enriched separate from the +ve terminal of the electrostatic separation tower is shown as trace (c). Finally, the ash residue from the coal-enriched separate from the -ve terminal is shown as trace (d).

The powder traces are quite similar to one another except that the peaks in trace (d) are more poorly defined suggesting poorer crystallinity of the clay minerals in the coal-rich sample.

X-ray diffraction traces of oriented specimens of the < 2 μm residues of the electrostatic separates are shown in Fig. 34. Two features stand out very clearly. Firstly, the clay minerals montmorillonite and kaolinite are present in both residues, but are much better crystallized and ordered in the ash-enriched sample. Secondly, a strong, sharp peak at 5.9 Å is present on the trace for the coal-enriched sample but not the ash-enriched sample. This peak is believed to represent a second order basal reflection of complex interlayered clay mineral that seems associated with the coal separate and not the ash separate. A small peak for this same material is also visible on the powder trace, Fig. 33(d). This particular peak is discussed further under Batch #2 coal.

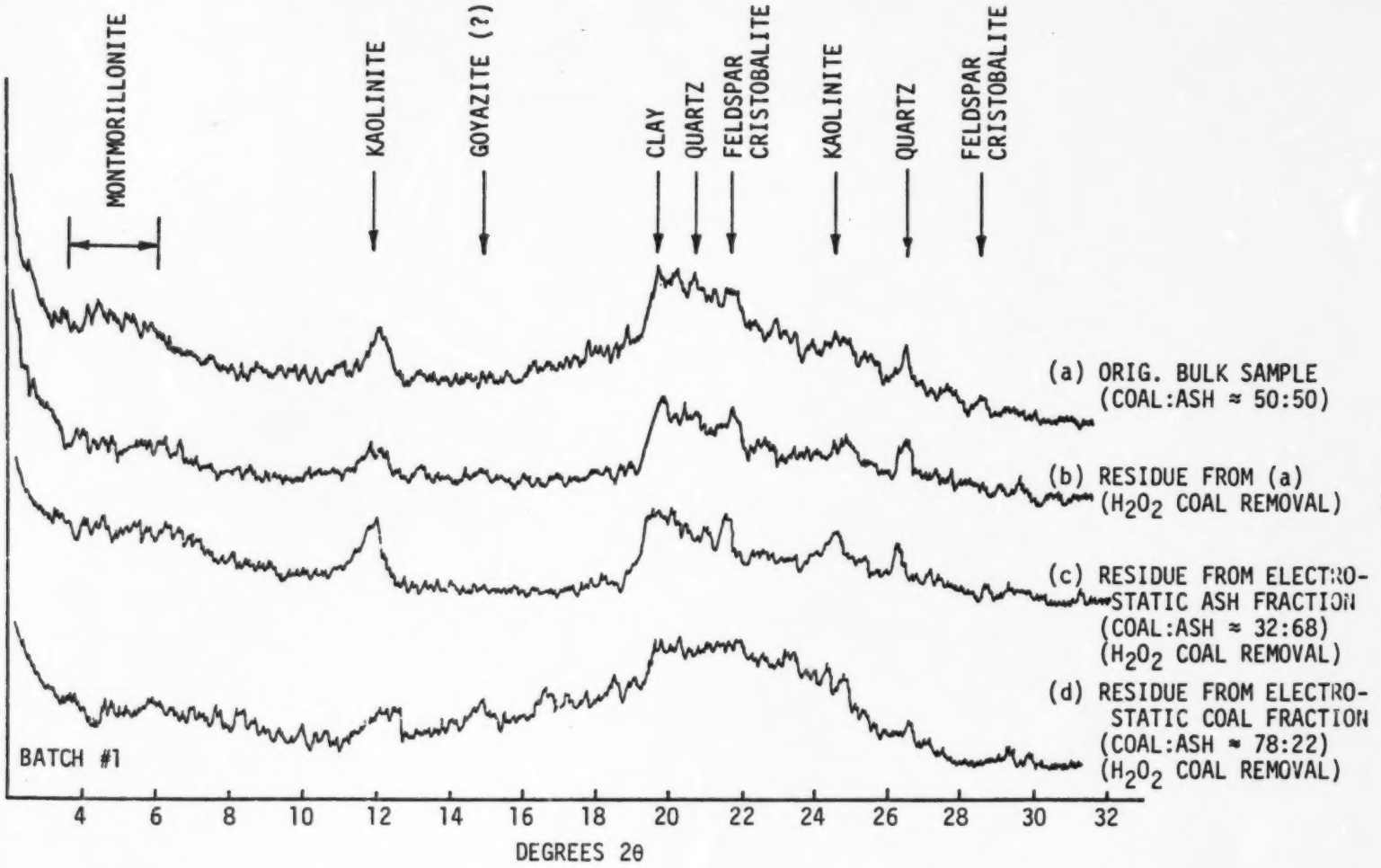


FIGURE 33. X-RAY POWDER PATTERNS OF HAT CREEK BATCH #1 COAL SAMPLES WITH COAL:ASH = 50:50, CuKα RADIATION

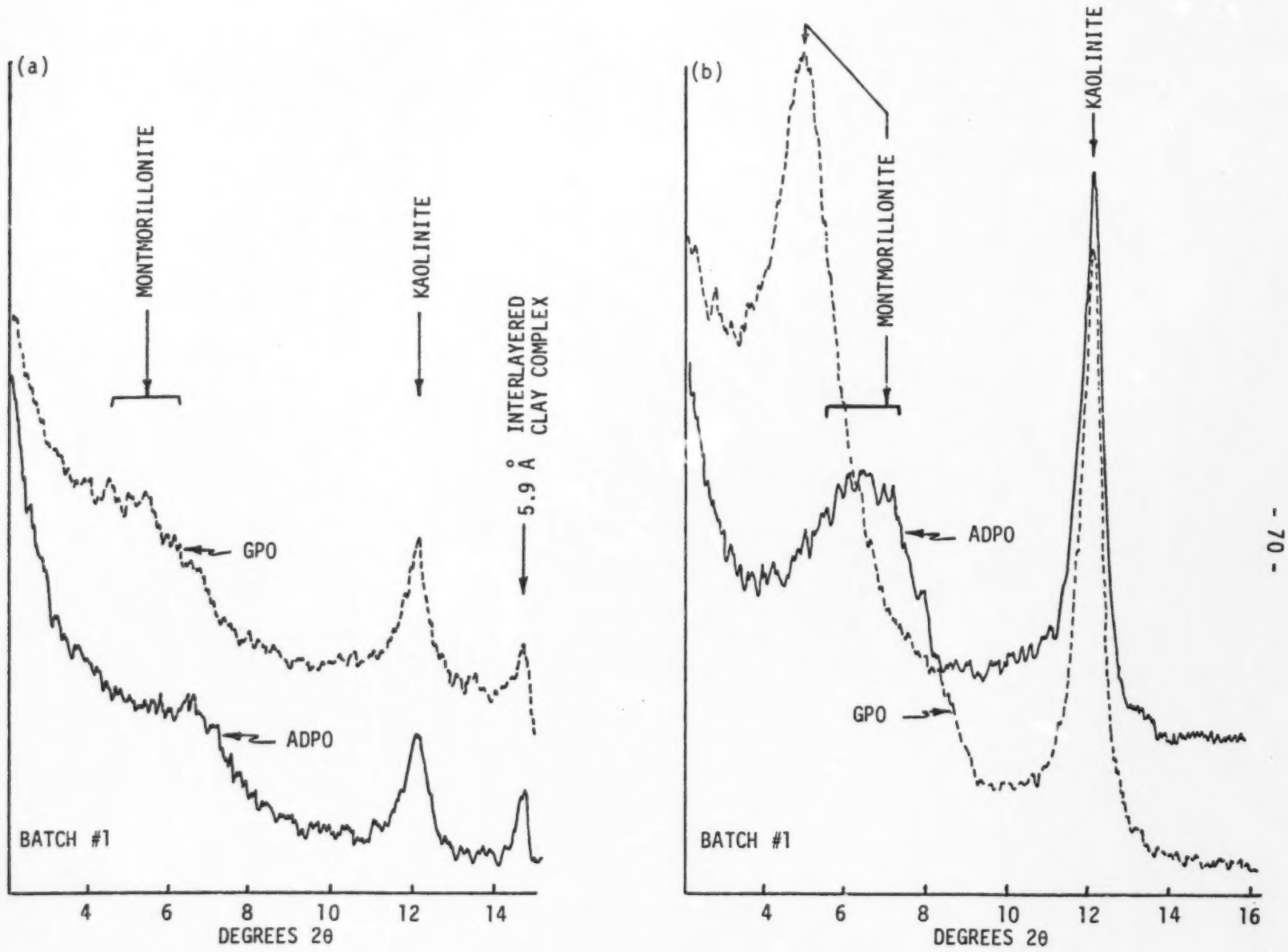


FIGURE 34. X-RAY DIFFRACTION TRACES OF ORIENTED, < 2 μm FRACTIONS OF RESIDUE FROM BATCH #1 COAL SAMPLES. COAL REMOVED BY H_2O_2 DIGESTION.

(a) RESIDUE FROM ELECTROSTATIC COAL RICH SAMPLE (COAL:ASH = 78:22)

(b) RESIDUE FROM ELECTROSTATIC ASH RICH SAMPLE (COAL:ASH = 32:68)

ii) Test Coal Batch #2 (Coal:Ash = 57:43)

Analysis of the Batch #2 test coal has been restricted to x-ray diffraction and glycol retention analyses carried out on pulverized bulk coal and two electrostatic separates.

X-ray powder patterns of the non-coal residues from two electrostatic separates (high ash from +ve electrode and high coal from -ve electrode) are given as traces (c) and (d) respectively in Fig. 10, p.20. The traces are similar to those for the bulk residue of trace (b) except that the 3.34 Å quartz peak in trace (d) seems somewhat enhanced.

X-ray traces of oriented specimens of < 2 μm residue are shown in Fig. 35. The samples are again dominated by kaolinite and montmorillonite with a significant amount of interlayered clay in the residue from the coal-enriched sample. More kaolinite may be present in Batch #2 than was observed in Batch #1.

It was originally thought that the 5.94 Å peak might be phosphate so the two separates were K^+ saturated and x-rayed again in the air dried state. A significant decrease in the size of this peak relative to the 7 Å kaolinite peak (Fig. 35) supports our contention that it is probably an interlayered clay of which montmorillonite is a component.

Removal of the coal from the various electrostatic separates by warm H_2O_2 digestion normally has a negligible effect on non-organic components of soils. Traces (a) and (b) on Fig. 36 illustrate the disappearance of one, isolated, sharp x-ray peak at about 4.24 Å, in the high ash separate, as a result of H_2O_2 digestion (oxidation). Washing the ash separate with 1 Normal KCl effected exactly the same disappearances as shown by trace (c). It is concluded that this interesting peak also represents an interlayered clay complex of which

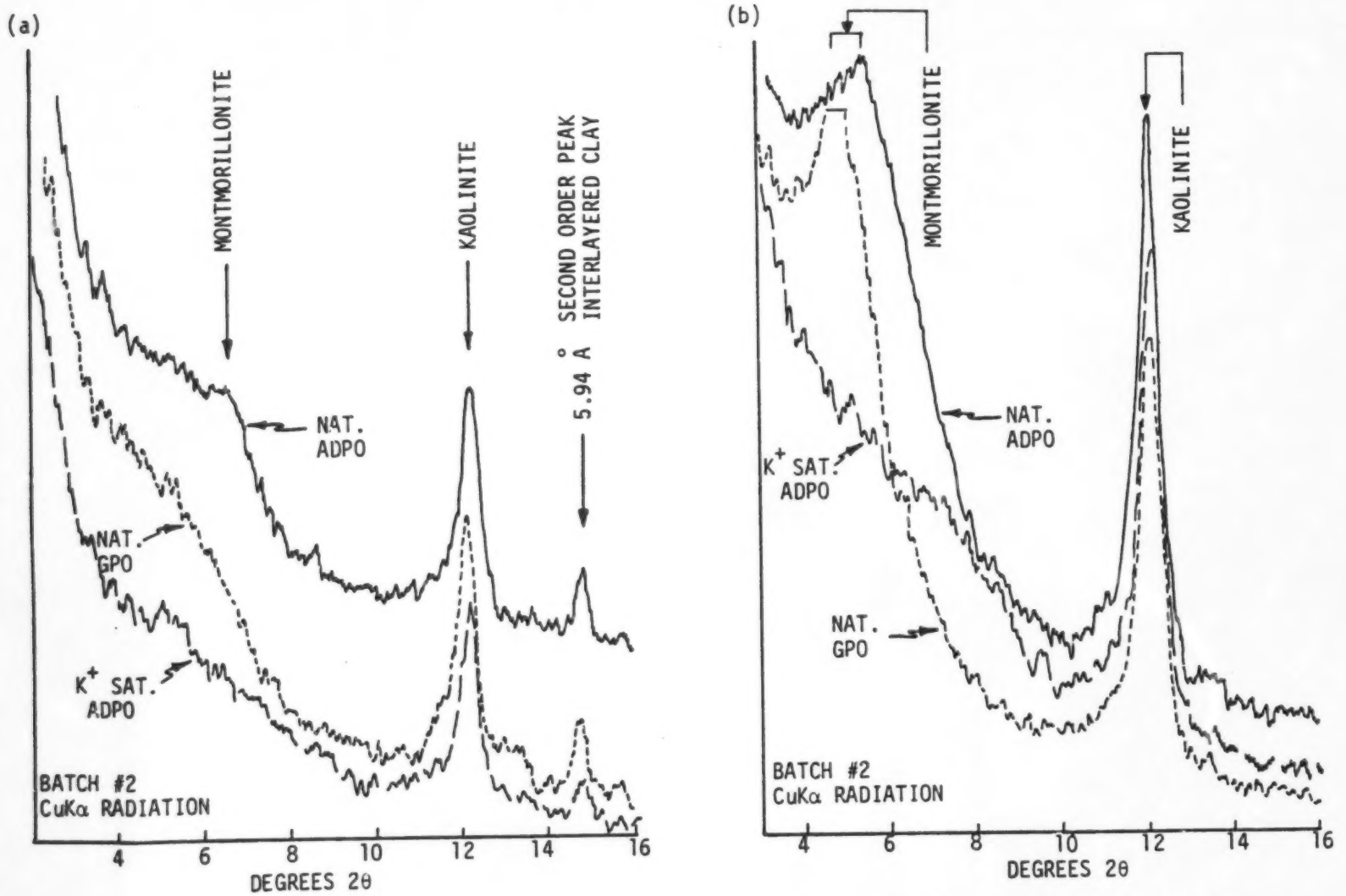


FIGURE 35. X-RAY DIFFRACTION TRACES OF ORIENTED, <2 μm FRACTIONS OF RESIDUE FROM BATCH #2 COAL SAMPLES: NATURAL AND K^+ SATURATED SAMPLES: COAL REMOVED BY H_2O_2 DIGESTION.
(a) RESIDUE FROM ELECTROSTATIC COAL RICH SAMPLE (COAL:ASH = 80:20)
(b) RESIDUE FROM ELECTROSTATIC ASH RISH SAMPLE (COAL:ASH = 36:64)

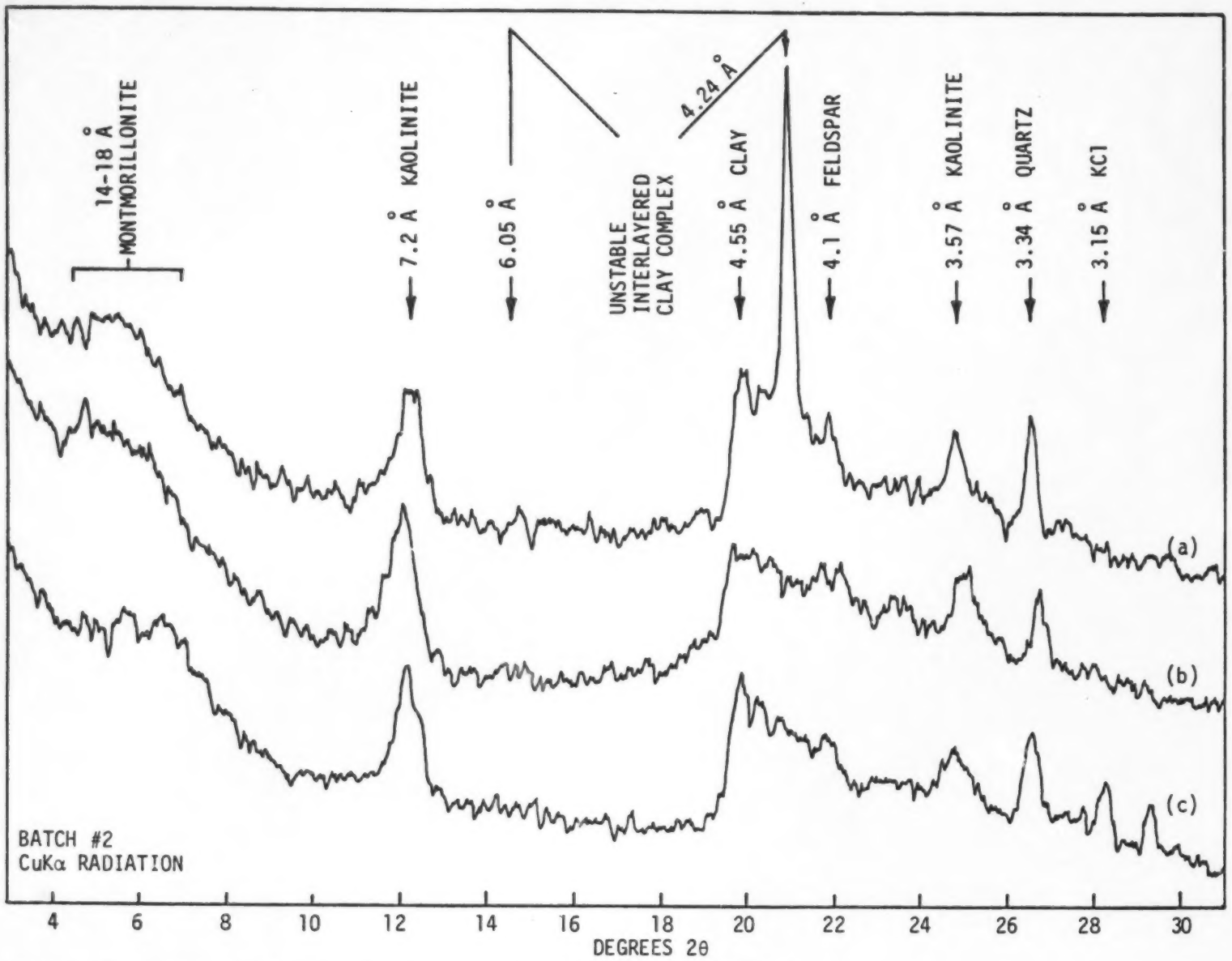


FIGURE 36. X-RAY POWDER PATTERNS OF HAT CREEK BATCH #2 COAL SAMPLES
(a) UNTREATED ASH SEPARATE WITH COAL:ASH = 36:64
(b) RESIDUE FROM ASH SEPARATE AFTER H_2O_2 DIGESTION
(c) KCl SATURATED ASH SEPARATE WITH COAL

one component is collapsible montmorillonite.

The residue from the high ash separate yielded a glycol retention of 96 mg/g compared to a value of 71 mg/g for the residue from the high coal separate. The clays contained in the coal-enriched separate are therefore less active than those contained in the ash-enriched separates.

G. CONCLUSIONS

1. The experimental work presented in this report covers two batches of Hat Creek coal which were compositionally somewhat different. The Batch #1 test coal consisted of ~ 50% ash which contained approximately 37% montmorillonite, 30% kaolinite and 30% quartz. The Batch #2 test coal consisted of ~ 43% ash which contained only 27% montmorillonite and relatively greater amounts of kaolinite and quartz. Other horizons of Hat Creek coal are known to contain zero montmorillonite.

2. In spite of the difference in the composition of the test coal, the results were substantially similar. In all cases the coal-rich fractions triboelectrified positively. However, it is recommended that a pilot plant be built to test on a larger scale all the main varieties of coal which may have to be beneficiated during the lifetime of the Hat Creek Mine. The electrostatic beneficiation process is based on the surface properties of the particles in contact, and changes in the composition could result in substantial changes in the triboelectrification properties.

3. The electrostatic beneficiation may be carried out directly on

particles which are ground to the size required in conventional burners. All tests covered by this report were carried out with minus 150 μm particles. This size range proved to

a) liberate the mineral matter sufficiently to reach beneficiation levels comparable to those obtained by washing

b) be suitable for conventional fluidization and tribo-electrification

c) have sufficient free fall velocity to allow for combined gravity and electric forces separation.

4. For an adequate triboelectrification of the Hat Creek fractions to be separated (coal-rich from ash-rich), it is necessary that the moisture content of the raw material be less than 3.5% (dry base) to prevent hydration of the montmorillonite and resultant loss of charge. Any moisture content below 3.5% (dry base) will ensure a very stable operation and consistency in the obtained recoveries.

5. The electric field intensities to be used in the separation must be as high as practical to eliminate corona discharges. Assuming that flue gas will be used for both the "inerting" of the separation cells and the fluidization, the recommended field intensity is a minimum of 2 kV/cm. This value is one order of magnitude smaller than the breakdown value in air. Furthermore, the use of the inert flue gas will ensure complete safety in case of an accidental electrical discharge.

6. The allowed relative humidity of the fluidizing gas in a pilot

plant will depend on the designed residence time of the coal particles in the fluidized bed prior to the free fall in the separation field. In the laboratory it was found that for a 5-minute residence time the relative humidity of the gas should be less than 19%.

7. The obtainable ash-free coal recoveries (hence the Btu recoveries) are highly dependent on the mineral matter content of the raw coal. The figure below shows the found relationships. From it, one may extrapolate to some extent the expected ash-free coal recovery for other mineral matter content percentages. As an example, the figure shows 85% ash-free coal expected beneficiation (88% Btu recovery) for a raw coal with 37% mineral matter.

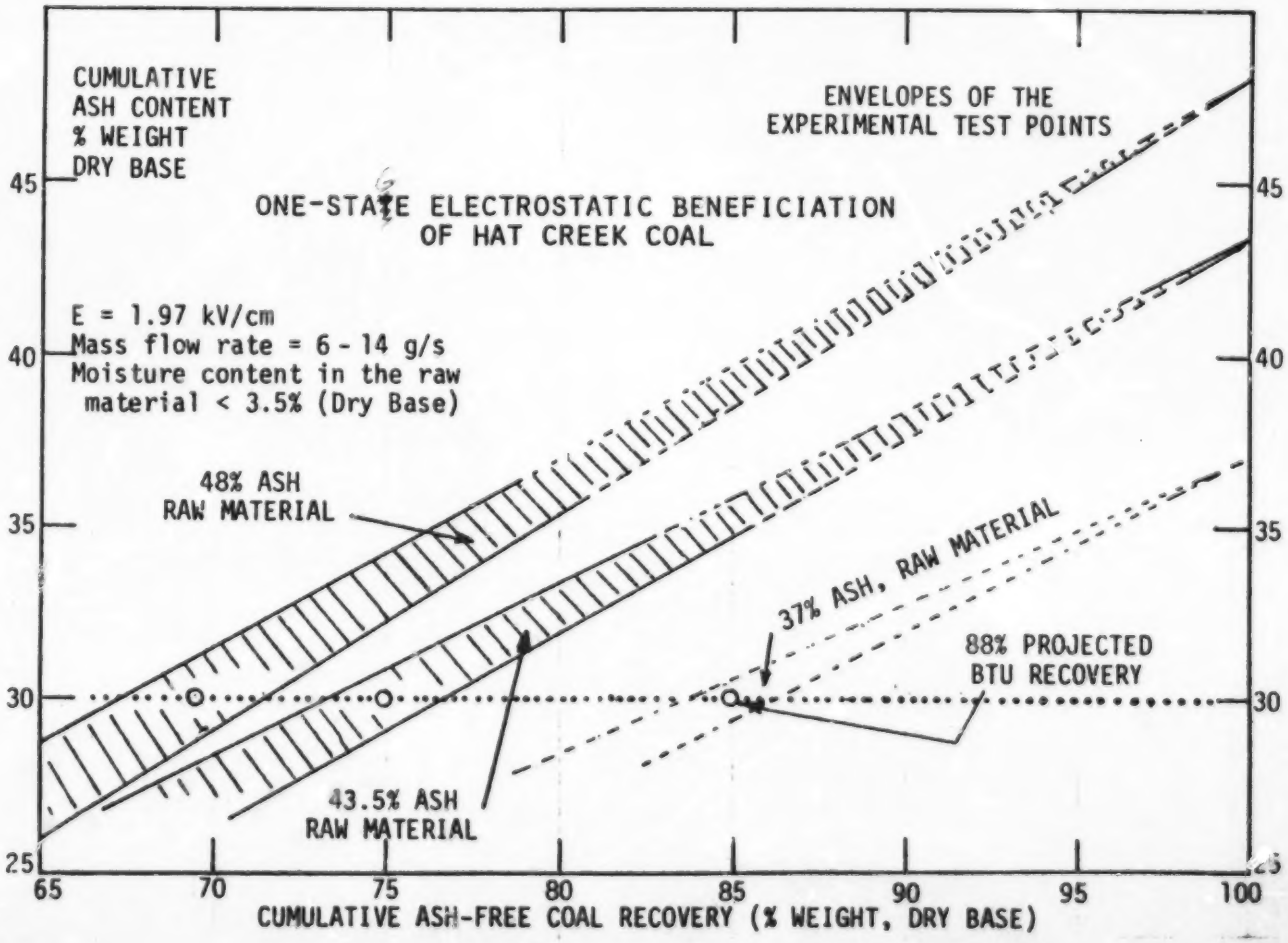


Fig 37.

8. The table below summarizes what one can expect to achieve with one-stage electrostatic beneficiation of the tested Hat Creek coal to produce coal with 30% ash (dry base).

	Average Experimental Values obtained for	
	Batch #1	Batch #2
Ash content in raw material [Weight %, Dry Base]	48.0	43.5
% Btu recovery based on the Dolmage Campbell formula Btu = 13003 - 151.98 x Ash %	76.5	80.0

9. The electrostatic beneficiation process shows some selectivity as to the mineral matter which goes with the ash-rich and coal-rich fractions. The inorganics in the electrostatic ash separates consisted of more montmorillonite and kaolinite than did the inorganics in the electrostatic coal separates which were enriched in quartz and cristobalite.

10. The alternative of using syntron feeders only, ought to be investigated fully. A few experiments carried out with the Hat Creek coal gave results fairly close to those obtained with fluidization. A syntron feeder alone will have the advantage of dispensing with the fluidization gas which will require some control of the humidity. However, this will have to be weighed against the excellent feed and triboelectrification control which can be achieved with a fluidized bed.

11. It is recommended that the decision on whether to plan for a single

or multistage electrostatic beneficiation be deferred until the entire spectrum of Hat Creek coal is tested in a pilot plant. In this project only Batch #1 of the coal tested indicated that worthwhile recovery gains may be achieved through multistage beneficiation.

12. It has been estimated, conservatively, that the overall dimensions of a one-stage unit to beneficiate 1000 ton/day would be 3 m x 20 m x (2.5 m high). The theoretical electrical power requirements would be negligible (less than 100 watt), and the theoretical fluidization power was estimated at ≈ 5 kW.

H. CONCEPTUAL DESIGN OF A PILOT PLANT TO BENEFICIATE THE HAT CREEK COAL

Figs. 37 and 38 show the details of a proposed design for a pilot electrostatic beneficiation unit to process 1000 tons of coal per day.

Fig. 37 is a top view of the unit showing the flow of the materials. Syntron feeders bring the raw coal into the fluidization area T, an extension of the main fluidized bed, for an initial triboelectrification. From there, the coal flows between the feed slots and fills the entire fluidized bed where the triboelectrification continues. The figures show the separated fractions carried away from the unit by means of belt conveyors. Assuming that the coal-rich fractions are removed by individual conveyors for each cell, the ash-rich fractions could be removed by a single conveyor as shown schematically.

However, the conveyors could be of any other type suitable for an integrated operation, e.g. hoppers combined with pneumatic transport

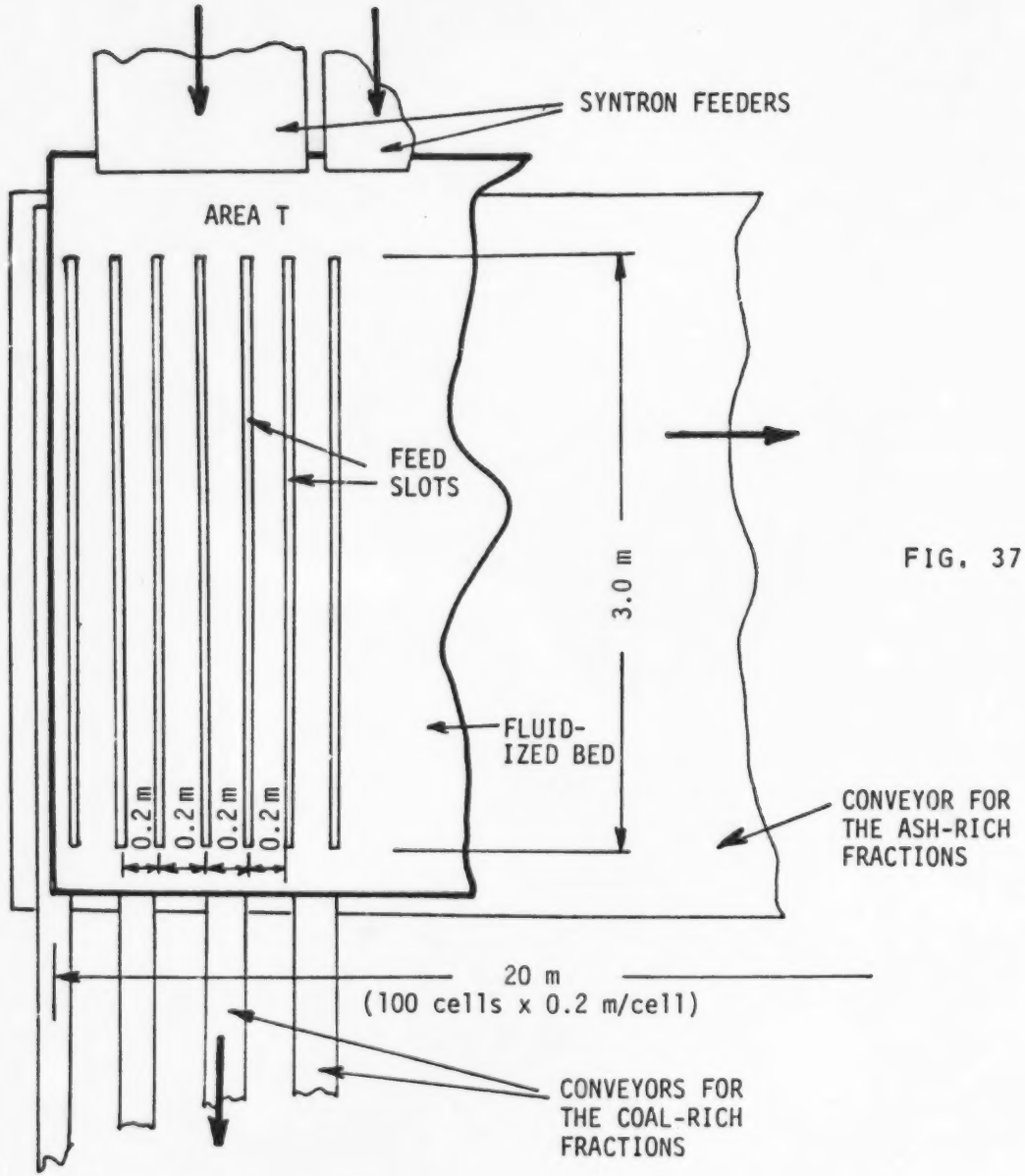


FIG. 37. ELECTROSTATIC BENEFICIATION UNIT FOR 1000 TON/DAY (SEMI-SCHEMATIC TOP VIEW)

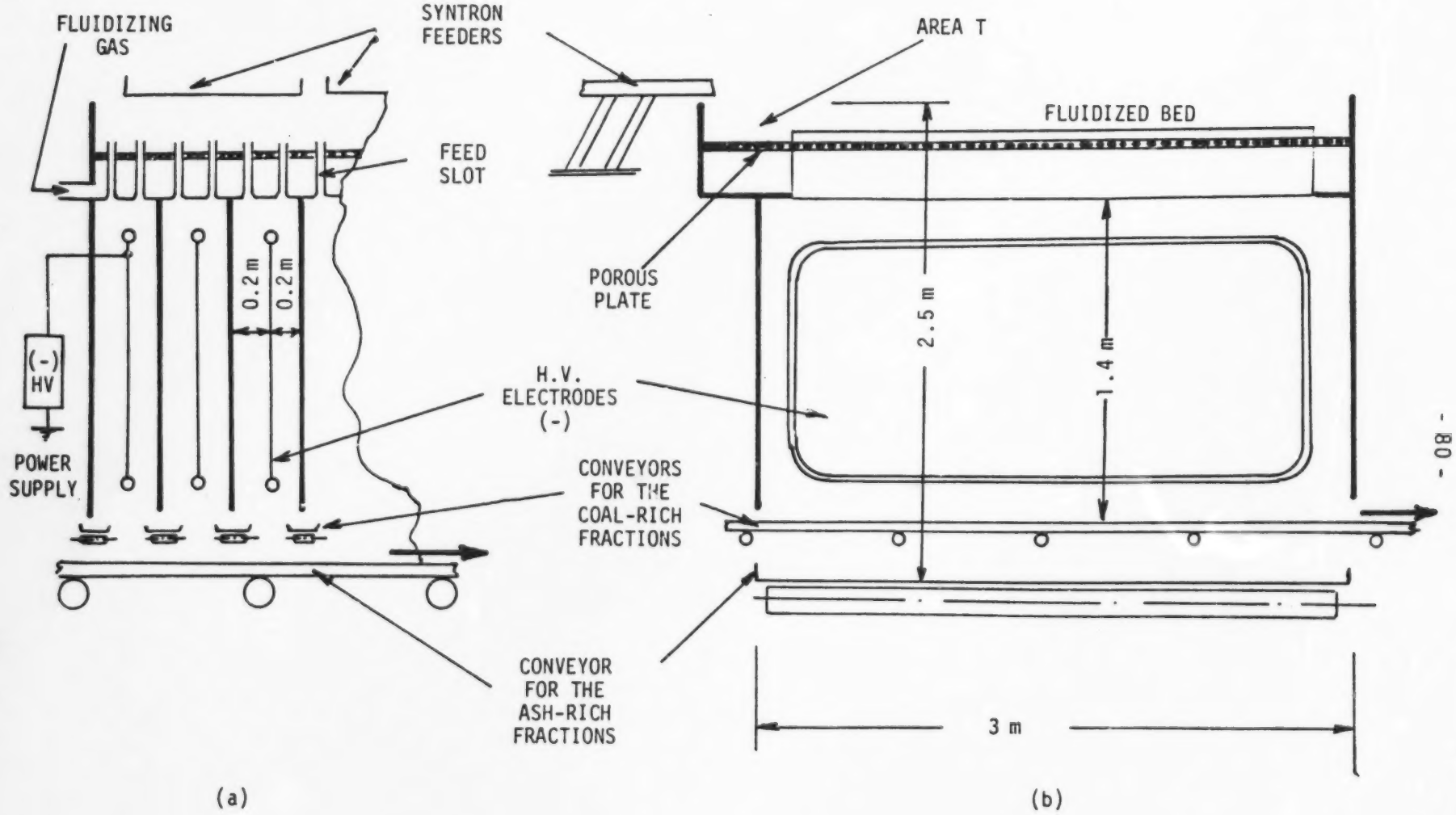


FIG. 38. ELECTROSTATIC BENEFICIATION UNIT FOR 1000 TON/DAY (SEMI-SCHEMATIC SIDE VIEWS)

or vibratory syntron conveyors. An important factor in the choice of the conveyor will be the location of the electrostatic beneficiation unit relative to the grinding and burning stations of the coal.

Fig. 38, (a) and (b), gives side views of the beneficiation unit. Beginning at the top, the main components of the unit are: the syntron feeder, the fluidized bed with the porous plate and feed slots, the high voltage electrodes alternating with grounded plates, and the conveyors.

Specifications for the 1000 ton/day unit

Raw material feed	1000 ton/day
Moisture content in raw coal	< 3.5% by weight, dry base
Overall dimensions of the electrostatic beneficiation volume	3 m x 20 m x (1.4 m height)
Fluidized bed depth	20 cm
Pressure drop through the porous plate	7 cm H_2O
High voltage power supply	60 kV, 100 mA
*Fluidizing gas	Flue gas of < 19% RH for 5-minute residence time
Gas fluidization velocity for raw material particles < 150 μm dia.	3 cm/s

*The R.H. will be a function of the residence time of the coal particles in the fluidized bed.

I. ACKNOWLEDGEMENTS

A grateful acknowledgement is made to Energy, Mines and Resources Canada and to B.C. Hydro. Their excellent cooperation and suggestions made this project possible.

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